THE GLACIAL HISTORY OF NANTUCKET AND CAPE COD

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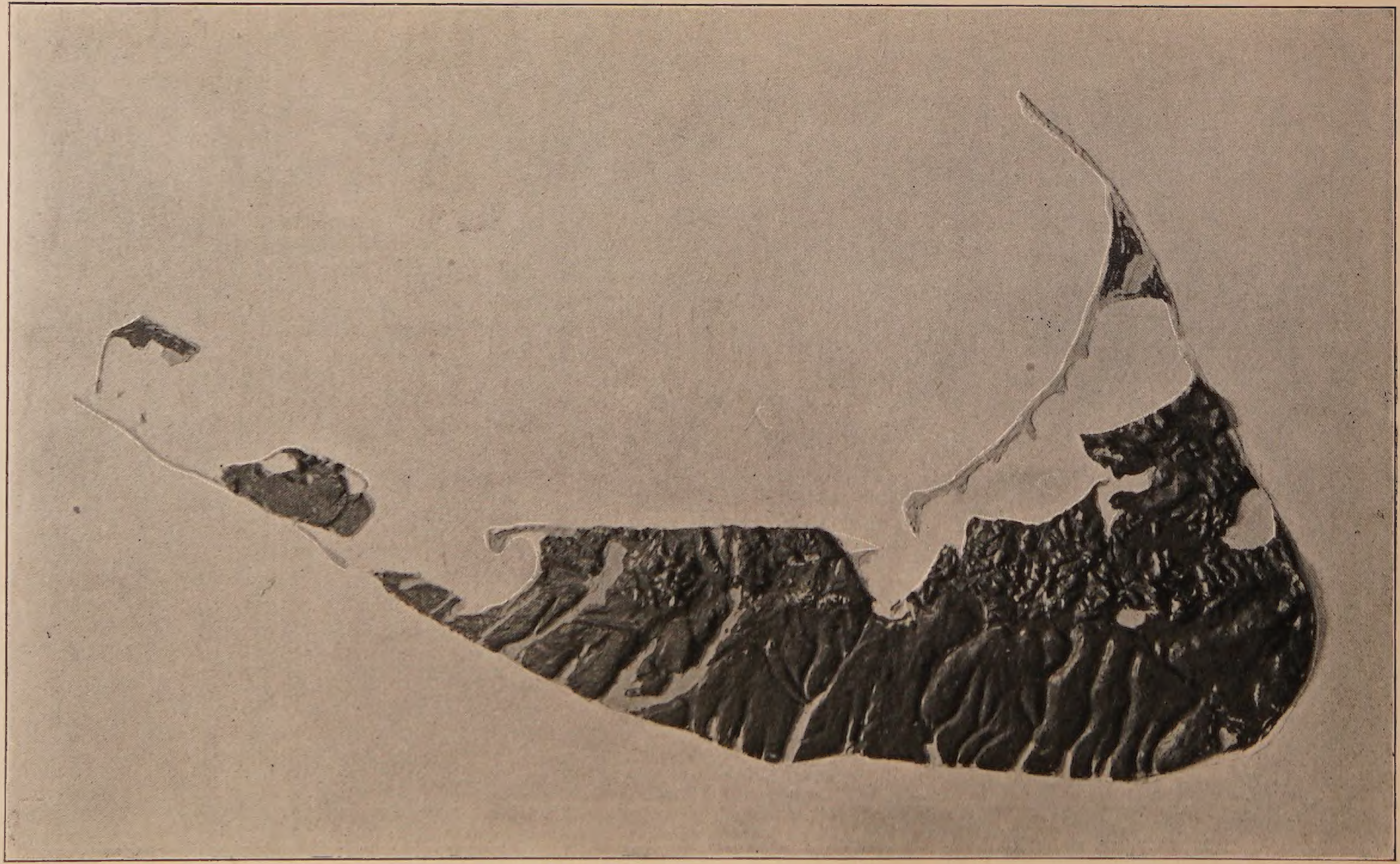

Relief Map of Nantucket.
Photograph of model made by the author.

COLUMBIA UNIVERSITY GEOLOGICAL SERIES. I.

THE GLACIAL HISTORY
OF
NANTUCKET AND CAPE COD

WITH AN ARGUMENT FOR A FOURTH CENTRE OF GLACIAL DISPERSION IN NORTH AMERICA

BY

J. HOWARD WILSON, A.M., PH.D.

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NOTE

In the geological discussions of the past fifty years, no one problem has excited more profound and widespread interest than that of the Glacial Period. The dissertation of Mr. J. Howard Wilson deals first with the crucial area at the extreme southeastern point reached by the continental ice-sheet in North America and presents in detail the local phenomena. From their study the author has been led to the investigation of a wider field, and has reached the conclusion that, in addition to the three great centres of glacial dispersion hitherto recognized, there was a fourth in Newfoundland. Many old difficulties in the interpretation of the glacial phenomena of the New England coast and of the maritime provinces are thereby cleared away, and an important addition is made to geological science.

J. F. KEMP.

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THE GLACIAL HISTORY OF NANTUCKET AND CAPE COD

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CHAPTER I

Introduction

The region taken for investigation, the results of which are comprised in the present paper, is the extreme southeastern portion of New England, and more particularly of the State of Massachusetts. Its coast is characterized by shallow waters, sandy shoals, capes, and rather low-lying islands, in which the harder rocks do not appear except in the glacial drift. The largest and most important of these islands are Nantucket and Martha's Vineyard, separated from Cape Cod on the north by Nantucket and Vineyard sounds.

Nantucket has the distinction of being the most southeasterly area of land in New England, and, exclusive of sand-spits, has a length of about twelve miles, with a width varying from two and one-half to five miles. Its form has been described by Professor Shaler as rudely crescentic. The surface is low and almost treeless, and the soil is generally sandy. The southern portion consists of a level prairie sloping gently to the south.

The northern portion is, however, more diversified, being traversed east and west by a chain of low, sandy hills.

West of Nantucket, and not differing greatly from portions of it in general character, are two small islands, Tuckernuck and Muskeget.

Still farther west, or somewhat north of west, lies Martha's Vineyard, of which Chappaquiddick Island is essentially a part. The former is the largest of the series which have been collectively termed the New England Islands.

Martha's Vineyard is triangular in form, with the apex of the triangle to the north, and has a length of about twenty miles, with a width of between nine and ten miles. This island is much higher than Nantucket, especially the western portion, and is more fertile and better wooded; but the central and southern regions consist of a great plain similar to that on Nantucket and with the same gentle slope to the south. Although none of the harder rocks appear *in situ*, much older formations are present than on Nantucket; Tertiary, Cretacic, and even older strata are found at certain points, especially at the famous section exposed in the Gay Head Cliffs.

The Elizabeth Islands are a group of small individuals constituting a chain which runs southwesterly from Wood's Hole on Cape Cod for a distance of sixteen miles. They are parallel to the western shore of Martha's Vineyard, from which they are separated by Vineyard Sound. Although nowhere very high, they are diversified by hills, and form the barrier between Vineyard Sound to the southeast and Buzzard's Bay to the northwest. They constitute, with Martha's Vineyard, the County of Dukes, Massachusetts.

Two other islands considered briefly in the following pages in reference to the glacial phenomena of this region are Block Island, between Martha's Vineyard and Montauk Point, the southeastern extremity of Long Island, and Fisher's Island, at the eastern entrance of Long Island Sound. The former belongs to the State of Rhode Island, and the latter to the State of New York.

Cape Cod is the long, curved arm which forms the southeastern extremity of the mainland of Massachusetts. As usually considered it includes all that region east of Monument River, a low pass almost sundering the narrow neck between Cape Cod and Buzzard's bays. The east and west portion of the Cape, which I will call Upper Cape Cod in distinction from the outer arm known as Lower Cape Cod, is a more or less sandy region, fertile in places, often well wooded, and containing numerous ponds. Its axis consists of a ridge of hills, the "backbone" of the Cape, terminating on the west in another ridge at right angles, running from Wood's Hole northward to the vicinity of Plymouth. South of the east and west ridge, the land slopes gently to the south, as is the case on Nantucket and Martha's Vineyard, but it is not so conspicuously a sandy plain. It is diversified by low hills and undulating areas, with numerous swamps and ponds.

Lower Cape Cod presents very different characteristics. It is a region of sandy plains, with little fertility. These plains upon investigation appear to be arranged in series having different elevations. The individual plains of a series as well as the several series may be separated from each other by valley-like depressions sometimes reaching nearly to sea level. Cape Cod on the mainland and Nantucket among the islands make up the area which has been made the subject of investigation by the writer, but the others are of necessity briefly treated upon the basis of work already recorded where they are involved in the glacial problems of the Nantucket and Cape Cod area.

Cape Cod, as will be seen, represents a retreatal stage of the ice from the Nantucket position. It involves some similar problems, such as the nature and source of this lobe of the great ice-sheet, and is able to furnish some additional facts.

This region is of peculiar interest as being the most southeasterly point reached by the ice on the present land surface of North America. Here were laid down the moraines and other formations of a part of that lobe of the great ice-sheet which lay out to sea off the New England coast farther north, and if this portion of the ice-sheet differed materially from the landward portion, the region might be expected to furnish some evidences of this difference.

Although most able and thorough work has been done in this field by Shaler, Woodworth, and others, the science of glacial geology is so young, and the field for investigation so large, that there would seem to be still many more facts to be gathered. As an example of this it may be pointed out that when Shaler did his important work on Nantucket, the results of which are comprised in Bull. 53, U. S. G. S., the kame hills, resembling as they do a terminal moraine, were thought to represent the southward limit of the ice at that place. Later, after additional facts had accumulated in regard to the nature of marginal features, especially the significance of the ice-contact slope, Woodworth showed that the ice reached some distance south of these hills.

In a similar manner, the phenomena presented by portions of Cape Cod were differently interpreted at different times.

The formations of Lower Cape Cod were considered by Chamberlin as possible glacial deposits of submarginal character, and that the ice-front here swung around to the north and was concentric to this portion of the Cape a short distance out to sea. Shaler considered these as of preglacial age masked under a thin mantle of drift. In 1896 Grabau, by a hurried survey of the region, came to the conclusion that the formations of this part of the Cape were in the nature of sand-plains formed in a body of standing water by streams coming from the ice-front.

I considered therefore that Nantucket and Cape Cod were well worth further investigations, and that investigations in the field might be rewarded by the discovery of additional facts of some importance.

This belief seems to have been justified. Not only were facts of additional local interest discovered, such as the exact position of the ice-front across the island of Nantucket, the existence of the Miacomet Valley lobe, and the relation of the old till clay and older topography to the late glacial formations, and the former existence in the Cape Cod region of a glacial lake, with a determination of its different stages; but also facts were discovered of broader and more far-reaching significance — those indicating the probable existence of a great Newfoundland ice-sheet which was the source of the ice on Nantucket and on Cape Cod.

I take the opportunity here to acknowledge valuable assistance in the preparation of this paper from Professor J. F. Kemp, Dr. C. P. Berkey, and Dr. A. A. Julien, of Columbia University, and especially from Professor A. W. Grabau of the same institution for many suggestions as to the problems involved and as to their solution. Other indebtedness through correspondence or otherwise is specifically acknowledged in the course of the following pages.

Any who may not be familiar with the principles and phenomena of glacial geology will find these fully set forth and treated in the following works: —

The Great Ice Age, by James Geikie, with chapters on the Glacial Phenomena of North America by Prof. T. C. Chamberlin, 1894.

Glacial Lake Agazziz, by Warren Upham, U. S. G. S. Monograph, XXV, 1895.

The Ice Age in North America, by G. F. Wright, with an appendix on The Probable Cause of Glaciation, by Warren Upham, 1896.

The Illinois Glacial Lobe, by Frank Leverett, U. S. G. S. Monograph, XXXVIII, 1899.

Glacial Formations and Drainage Features of the Erie and Ohio Basins, by Frank Leverett, U. S. G. S. Monograph, XLI, 1902.

The Glacial Geology of New Jersey, by R. D. Salisbury, assisted by H. B. Kümmel, Charles E. Peet, and George N. Knapp, Vol. V. of the Final Report of the State Geologist of New Jersey, 1902.

Geology, by T. C. Chamberlin and R. D. Salisbury, Vol. III, Earth History, 1906, pp. 327–516.

CHAPTER II

The Wisconsin Ice-sheet

THE NANTUCKET AND LONG ISLAND LOBES

That portion of the Wisconsin ice-sheet which formed the morainal accumulations and glacial features of southeastern Massachusetts, including Cape Cod and the neighboring islands to the south and southwest, has been found to be composed of two different lobes, so distinct and from such widely separate sources as to constitute almost distinct ice-sheets. They will be referred to in this paper as the Nantucket and Long Island lobes. Upham and Woodworth both recognized the former existence of the two lobes with the interlobate moraine, but apparently did not appreciate the full significance of the phenomena. They describe them rather as lobes formed by a reëntrant angle in the ice-front and not of great extent, and of far distant and widely separated sources, as will be shown was probably the case.

These two lobes were intimately associated and had each at least two corresponding stages. One was marked by a maximum advance when the outer moraines were formed, and the other by a definite period of halting in the retreat from this region in which was formed the line of inner moraines.

The two stages of the Nantucket lobe will be called (1) the Nantucket stage, and (2) the Cape Cod stage; while the corresponding stages of the Long Island lobe will be termed the Block Island-Martha's Vineyard stage and the Fisher's Island-Elizabeth Islands stage.

THE EVIDENCE IN SUPPORT OF TWO LOBES

While from glacial groovings and striæ left on the surfaces of the hard rocks over which the ice moved, we know definitely that the motion of the great Wisconsin ice-sheet was in a general southeasterly direction as it passed seaward from the mainland of New England, the absence of the harder rocks on Cape Cod or the islands to the south makes it impossible to obtain any such direct evidence as to the direction of its motion in these regions. There are reasons however for believing that that portion of the ice-sheet which formed the Nantucket and Cape Cod moraines and associated formations came from some point in the neighborhood of Newfoundland, and had a general direction of motion somewhat west of south.

The reasons favoring the belief in this great difference in source and direction of motion of the ice-sheet in such adjacent regions will now be considered.

1. It is probable that the ice extended much farther out to sea than is generally supposed, although both Professor Agassiz and Mr. Warren Upham ('99, p. 82) recognized the probable great seaward extent of the continental glaciers.

The shoal water at considerable distances from the coast would in no way interfere with the extension of the ice-sheet in that direction. The 100-fathom line is found 150 miles east of Nantucket, and with the exception of one deeper spot in the Gulf of Maine and one between Nova Scotia and Newfoundland, is nearly that distance from the coast all the way to the Grand Banks. The Muir Glacier in Alaska enters Glacier Bay with a thickness of about 1000 feet, and is consequently not afloat in 600 or 700 feet of water. Such an ice-sheet as the Wisconsin glacier, a mile or more in thickness, in New England would have found no difficulty in extending seaward at least to the 100-fathom line. During the elevation of the northeastern part of the continent which existed in Wisconsin times, there is reason to believe that the land mass of Newfoundland extended much farther to the east than at the present day, furnishing a region from which a portion of the ice could well have moved in a south or even southwest direction.

In support of this view and to show that the action of the ice was in nowise feeble at the most eastern extremity of its front, now known to us through marginal accumulations, we should call to mind the kame hills at Sankaty Head, one of the highest points on Nantucket, and the contact slope of Tom Never's Head three miles to the south, the best developed on the island, and sixty feet above the fosse.

2. The general direction of the ice-front from the most northern point of Martha's Vineyard, which as will be shown later was the western limit of what will be termed the Nantucket lobe, was southeast to Tom Never's Head, where it passed out to sea for an unknown distance. Now considering in general that the motion is approximately at right angles to the front, this would indicate a source for this portion of the ice-sheet somewhere considerably east of north.

3. There is an abrupt change of direction in the ice-front on Martha's

Vineyard. On the eastern half, the moraine has a northwest and southeast direction, while on the western half a southwest and northeast direction, the two portions meeting in an abrupt angle forming the northern point of the island and determining its triangular shape. It will be noticed that this angle and point lie directly south of the interlobate moraine, which is next to be considered.

4. There is an interlobate moraine extending in a southerly direction from the neighborhood of Plymouth and Manomet Hill to Wood's Hole. This ridge is pitted with numerous kettles and covered with large boulders and is of a distinctly morainal nature. Contact slopes occur on both sides at different points as at Falmouth and West Falmouth, and on the high land at Pine Hill between Cataumet and Sandwich. They show that the ice must have come from both directions so as to form an interlobate moraine.

5. The presence of the red shaly limestone containing Cambric fossils in the drift at Highlands in North Truro. One pebble of this rock was also found just east of the contact slope at Pine Hill. The nearest known locality for this red Cambric limestone is Newfoundland, with the single exception of that at North Attleboro near Boston, which could hardly be the source of the material found at Highlands.

It is interesting to note in this connection that as long ago as 1888 (Report on the Geol. of Martha's Vineyard, U. S. G. S. 7th Ann. Report), Professor Shaler noticed the difference in morainal material between the eastern and western parts of Martha's Vineyard. He says (p. 325), "The pebbles on the eastern side of the island are more varied in their mineral constitution, closely resembling those of Nantucket."

The facts given briefly above seem ample to justify the belief in the view that the moraines of Nantucket and Cape Cod were formed by a lobe of ice of such large dimensions as almost to form a distinct ice-sheet which came from the direction of Newfoundland, while the glacial features west of the Plymouth-Wood's Hole moraine, including the western half of Martha's Vineyard, are the result of what will be termed the Long Island lobe of the main ice-sheet.

It remains now to consider the relations which the two lobes bore to each other from the time of their maximum advance, through their successive retreats, to the time of their final disappearance from this region.

RELATIONS OF THE NANTUCKET AND LONG ISLAND LOBES

At the time of maximum advance, the Nantucket lobe formed, as we have seen, the morainal features of Nantucket and those as far west as the northern point of Martha's Vineyard, constituting the Nantucket stage. At the same time the Long Island lobe held its front along the western side of Martha's Vineyard through Block Island, entering Long Island at Montauk Point, and forming the outer moraine from that point to New York,[1] constituting the Block Island-Martha's Vineyard stage. (Plate II *a*.)

The retreat of the front of the Nantucket lobe to Cape Cod, where it remained stationary for some time, formed the Cape Cod moraine, and constituted the Cape Cod stage. It was accompanied by the retreat of the western or Long Island lobe. The latter maintained for a time a stationary front along the line of the Elizabeth Islands, southern Rhode Island, Fisher's and Plum islands, and formed the moraine in those regions. Its westward continuation afforded the innner moraine of Long Island, and constituted the Fisher's Island-Elizabeth Islands stage of the Long Island lobe. (Plate II *b*.)

The Plymouth-Wood's Hole interlobate moraine was of course formed between the Nantucket and Long Island lobes, the southern portion, from Monument River to Wood's Hole, being interlobate only during the Nantucket stage, but a terminal moraine of the Long Island lobe during the subsequent stage.

The contact slopes already mentioned on both sides of the moraine also indicate its interlobate character. A careful study of the material, allowing for a certain amount of mixture, would probably result in the discovery that it was of a different character, and from a different source on the west side than on the east side as suggested by the discovery of the Cambric pebbles near the contact slope, noted above, on the east side near Pine Hill.

It is most reasonable to suppose that the retreat of the Long Island lobe to the Fisher's Island-Elizabeth Islands position was contemporaneous with the retreat of the Nantucket lobe to the Cape Cod position, the retreat in both cases being undoubtedly due to the same general causes. The fact that the landward ice was more persistent, retreating in this region only to the Elizabeth Islands, while the Nantucket glacier had retreated to the neighborhood of Sandwich and Barnstable, is further borne out by the southeasterly drainage from the southern part of this morainal ridge as shown in such a case as the chain of ponds heading in Long Pond in the vicinity of Falmouth. Thus while the ice still held on to the west side, it had already retreated on the east.

This portion of the moraine was therefore at this time terminal to the western lobe with an overwash and drainage in a southeasterly direction in the region previously occupied by the ice of the Nantucket lobe.

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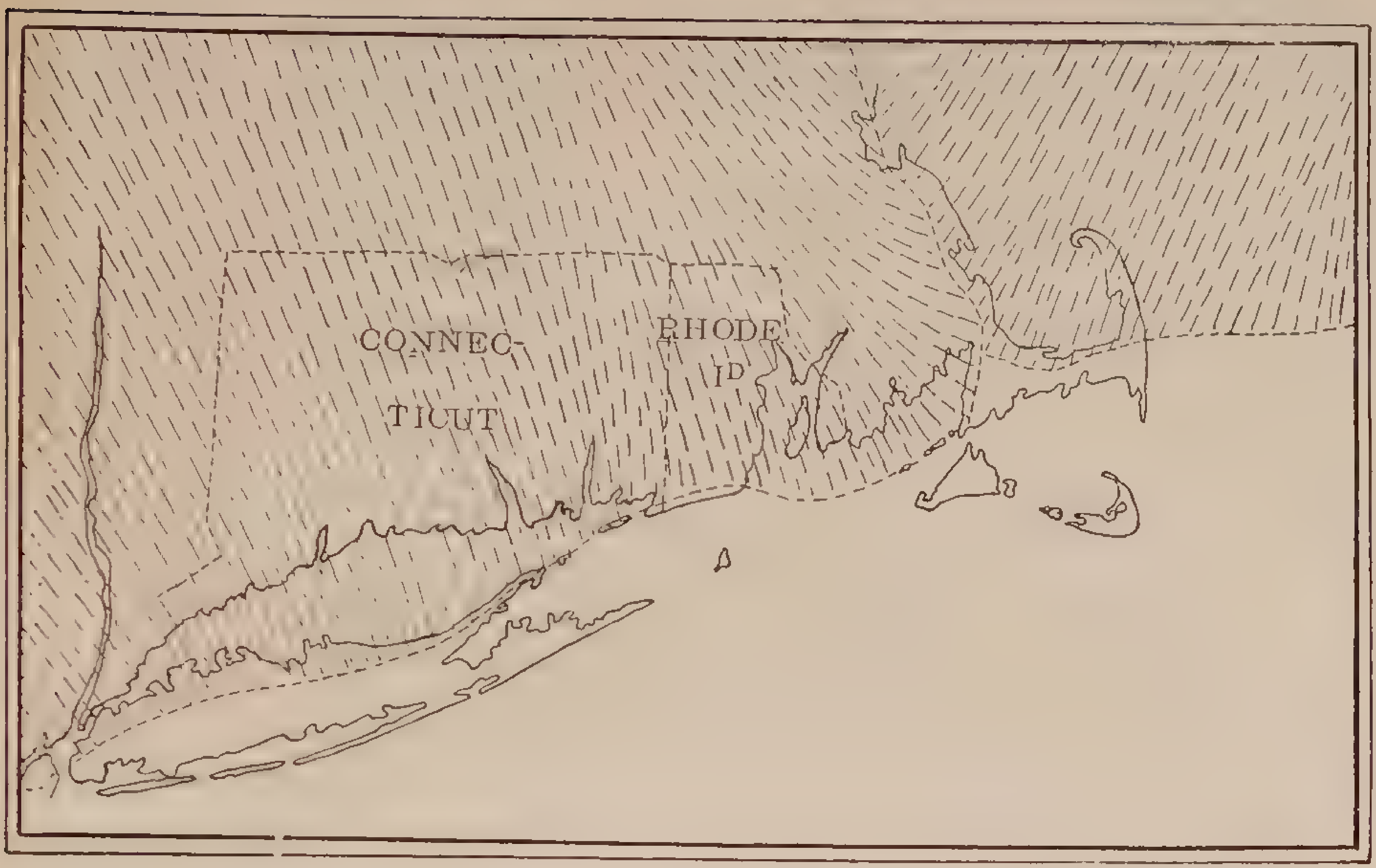
[1] Woodworth shows that the one crosses the other just east of Brooklyn.

PLATE II.



b.

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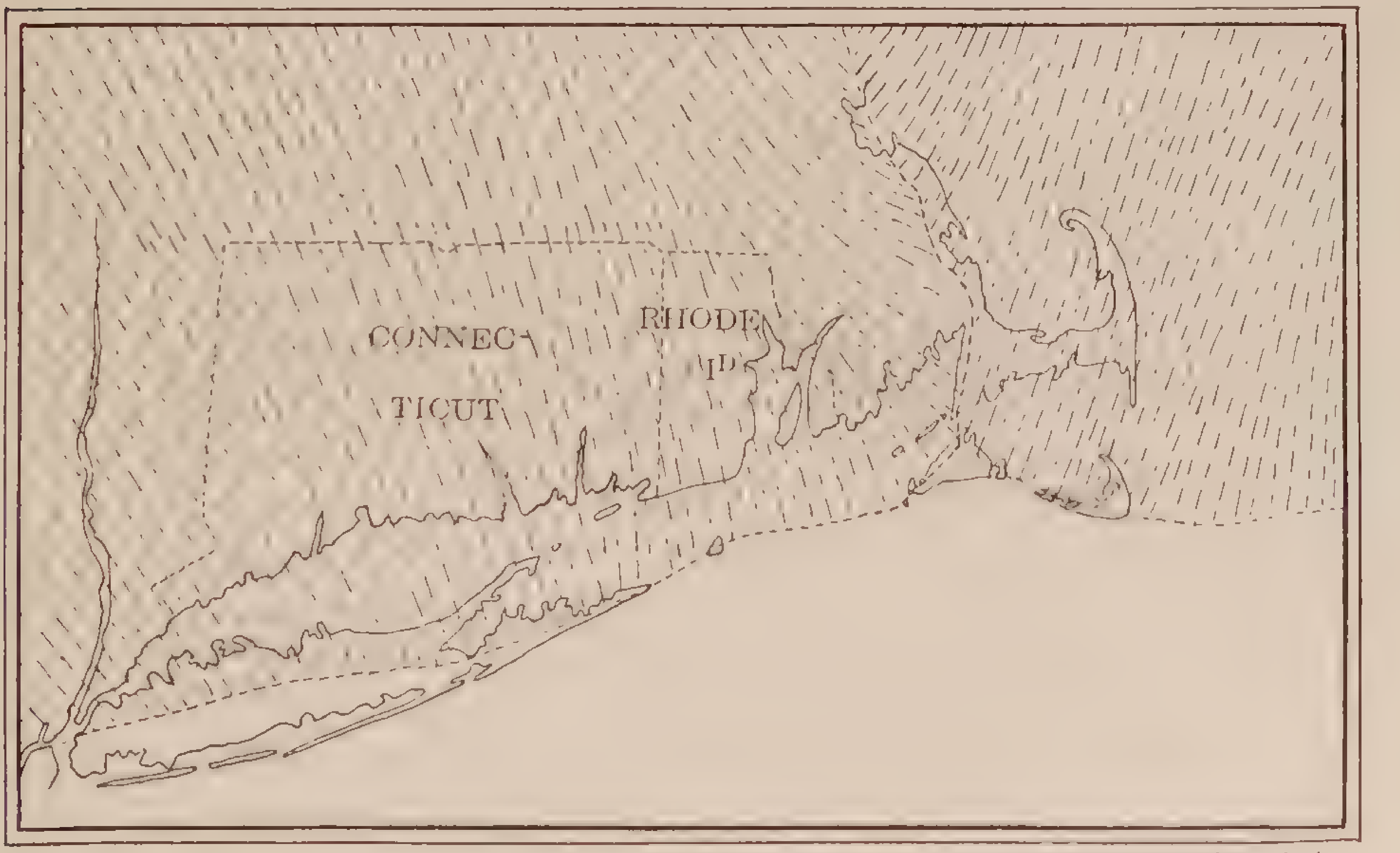


a.

J. Howard Wilson, Del.

Relation of the Nantucket and Long Island Lobes.
(*a*) Maximum stage (*b*) Retreatal stage.

That the landward ice would prove more persistent was to be expected, and that it was so will be further shown in the discussion of the sand-plains of lower Cape Cod, when it appears that this lobe filled Buzzard's Bay, and consequently closed the low pass of Monument River through the Cape Cod moraine at a time when the Nantucket lobe had already begun its final retreat from that position.

The fact, as will be shown later, that the moraines of the area under consideration, terminal and interlobate, are noticeably built upon ridges of older land which exactly coincide with the lines of the moraines, however varied as to direction, points strongly to the supposition that these ridges were squeezed up by the ice-thrust, either in late Wisconsin times or by an earlier ice-sheet, the frontal lobes of which occupied the same positions.

CHAPTER III

PREGLACIAL AND EARLY GLACIAL FORMATIONS OF NANTUCKET

THE general physical features of the island of Nantucket have become familiar to the writer through many summers spent upon their study, but the summer of 1904 was devoted to a critical examination from a geological standpoint.

The real nature of the main features of the island has long been known; it is, as is well known, part of the terminal moraine of the last advance of the great continental ice-sheet or Wisconsin glacier, and presents perhaps some of the best-developed morainal features to be found in any part of the world. It is of special interest in this connection as Professor Shaler has pointed out (Shaler, '89, p. 11), because it is the most southeastern point reached by the continental ice-sheets on the present land of North America. The general geology of Nantucket is so well known through the reports of Professor Shaler and others (Shaler, '89), as to make it unnecessary to treat it in detail in this paper. There are, however, some special features presented by Nantucket which have been somewhat difficult of interpretation, and these will be made the subject-matter of the present paper and briefly discussed.

PREGLACIAL FORMATIONS

The oldest beds exposed or known to exist in the formation of Nantucket are certainly not older than the Cretacic, and that age has been claimed for some of the clays which underlie the glacial drift, but up to the present time there seems to be no proof of any kind to support this view. Dr. Arthur Hollick, who has made a study of the Cretacic outcrops occurring in the different islands, from Long Island to Nantucket, informs me that he has found no evidence favoring the existence of beds of this age on the latter island. He says also that no Cretacic material has been found east of Buzzard's Bay and Martha's Vineyard (Hollick, '02, p. 384.)

The brown clay reported by Messrs. Desor and Cabot in 1849 (Desor and Cabot, '49), and subsequently by Mr. S. H. Scudder in 1874

(Verrill, '75), as forming the lowest bed in the section exposed at Sankaty Head, and which has considerable dip to the southwest, has been supposed by some to be of Cretacic age. It has also been considered as the eastern limit of a syncline, appearing again on Martha's Vineyard as the known Cretacic clays, the trough extending under Nantucket and the region between Sankaty Head and Martha's Vineyard (Shaler, '89, p. 31). This clay is not now exposed, nor has it been for a considerable number of years. Several investigators at different times, as well as myself in 1904, have failed to find it in the bluff at Sankaty Head, although we have dug as deep as it was possible to excavate with ordinary means.

The southwestward dip of this bed, with the cutting back of the bluff by the sea since its first discovery in 1849, have probably caused this bed to disappear far beneath the level of the beach sands, as will be shown later. No fossils have been reported from this bed, and nothing more is known of it, and the failure to find it of recent years makes further investigation impossible. I am strongly of the opinion, however, that it does not differ essentially from clays of glacial origin which appear in other parts of the island, and which will be treated of later on, together with some of the facts which seem to warrant correlating this Sankaty Head clay with them.

With the exception of these doubtful Cretacic clays and some formations such as beaches which are of quite recent origin, the material of which Nantucket is formed is of undoubted glacial origin. The problem becomes reduced then mainly to the interpretation of the phenomena resulting from the action of a great continental ice-sheet along its southern margin, or the resultant of two or more successive ice-sheets with any interglacial erosion or deposition or changes of level since the beginning of glacial times.

EVIDENCE OF AN OLDER ICE-SHEET

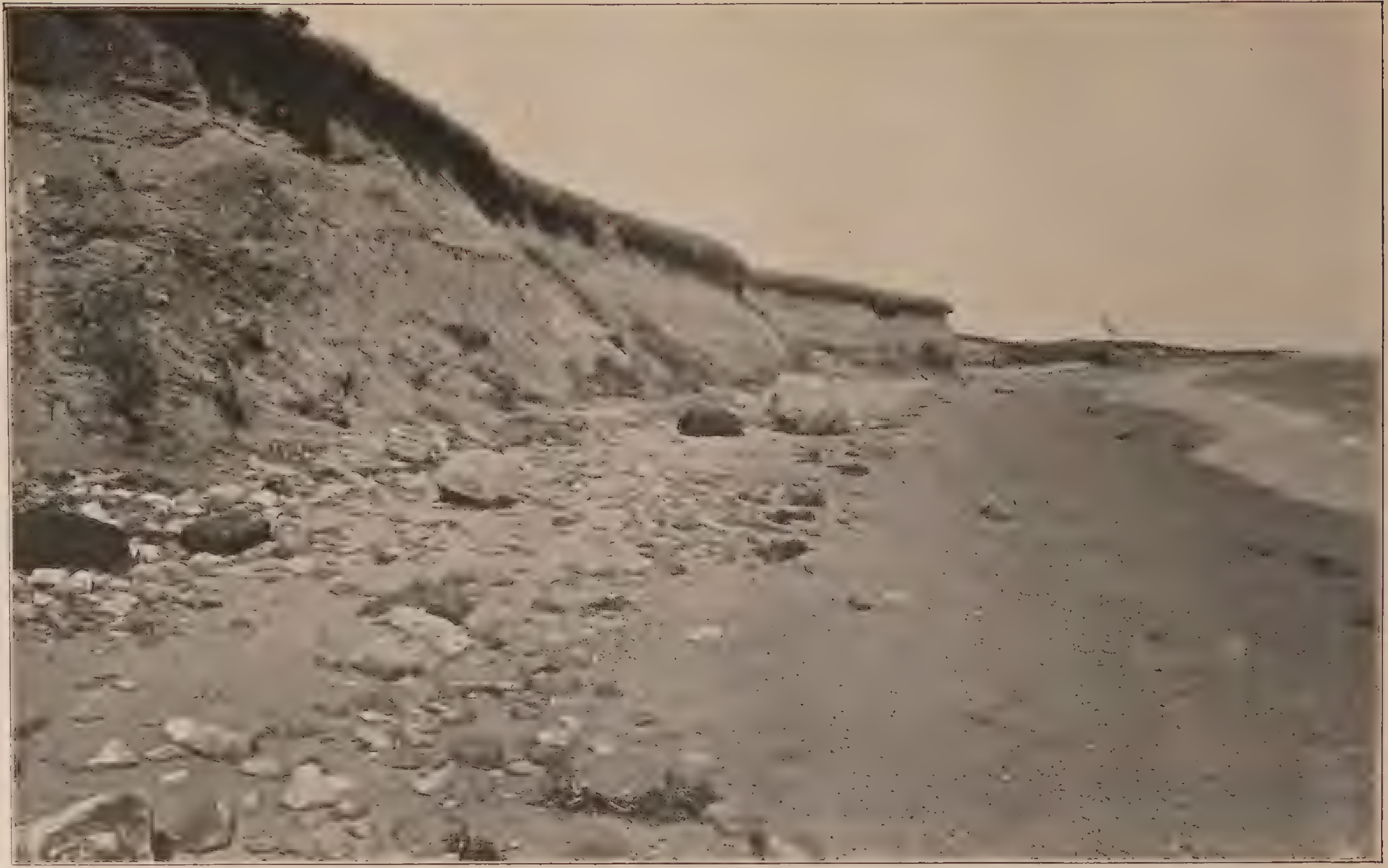
The main physical features of Nantucket which produce its present characteristic topography are the result of the last advance of the ice, or Wisconsin epoch.

Underlying this Wisconsin drift are bluish or yellowish brown clays (according to the amount of oxidization) which seem unquestionably to be of the nature of a ground moraine, formed by one of the pre- or early Wisconsin ice-sheets. This old till extends some distance beyond the extreme position reached by the ice in the last advance, as shown at the southern end of Hummock Pond, extending for an unknown distance beneath the wash-plain and the sea to the south, and presents a very unconformable surface to these later deposits. Where sections are obtainable, it often shows a certain amount of folding, due undoubtedly to the push of the Wisconsin ice. (Plate III.)

In most parts of the island this clay sinks below sea-level, or stands so low that its more or less undulating surface does not materially disturb the characteristic morainal features of the Wisconsin drift; but in some parts of the island, especially in the neighborhood of the town and westward to Clark's Cove, the western arm of Hummock Pond, it rises in places to considerable elevation, its eroded surface forming a pre-Wisconsin topography of hills and valleys before the advance of the late Wisconsin ice. This pre-Wisconsin topography is masked and more or less concealed by the later drift, and the latter is, in turn, in certain regions prevented from exhibiting the normal features we should expect to find, by its deposition on the irregular surface of the old till.

It is the presence of this old till as a topographic feature beneath the later drift which has produced most of the puzzling elements in the tracing of the exact position of the Wisconsin ice-front at the time of its maximum extension on the island, and in the disturbance of the characteristic features of the marginal accumulations. The presence of this old clay close beneath the surface may often be detected, as Professor Shaler has remarked (Shaler, '89, p. 17), by the change in the character of the soil, but it will be treated of hereafter only when it rises to such an elevation as to enter as an important element in the present topography.

PLATE III.



SOUTH SIDE OF COSKATA ISLAND, LOOKING EAST.

CHAPTER IV

THE SANKATY HEAD BEDS, NANTUCKET[1]

HISTORICAL

THE fossiliferous beds at Sankaty Head have been a subject of interest since first reported by Messrs. Desor and Cabot in 1849. The section has been referred to by Professor Shaler ('89, p. 30), as "one of the most important on the New England coast." The beds have been visited and studied by a number of well-known scientists, among whom were Professor A. Hyatt, Mr. C. H. Merriam, and Mr. Sanderson Smith, in 1875; Mr. S. H. Scudder and Mr. Richard Rathbun, a short time afterward; and, still later, Dr. F. J. H. Merrill and Dr. Arthur Hollick. While these investigators have added to the number of species reported from these beds by Messrs. Desor and Cabot, they have differed somewhat in their descriptions of the beds, and in their interpretations of the phenomena presented.

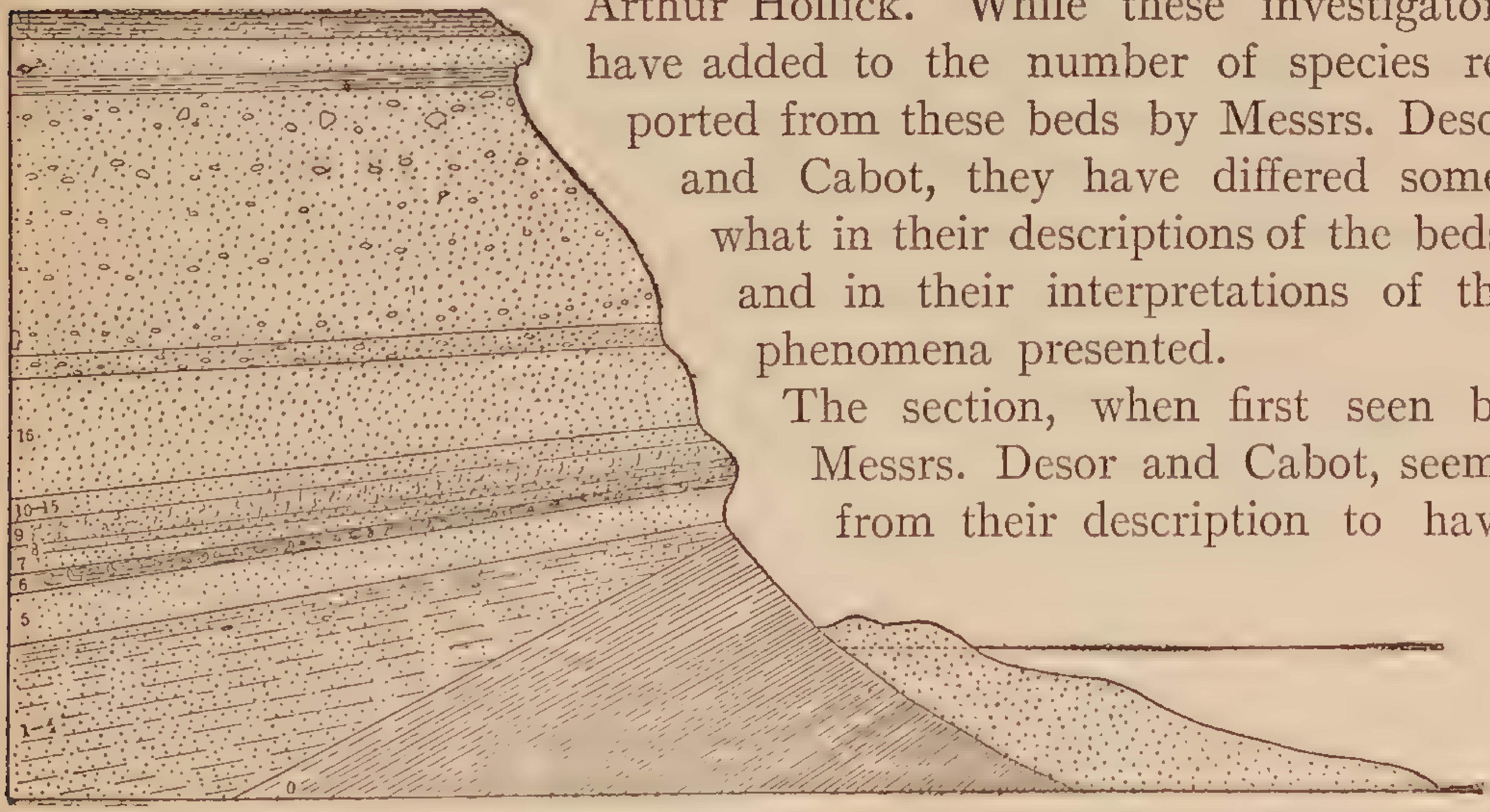


FIG. 1.

The section, when first seen by Messrs. Desor and Cabot, seems from their description to have presented very much the appearance shown in Fig. 1, the lower clay forming twenty feet of the lower part of the section and being overlain, apparently unconformably, by the lower sands and gravels. The section at this time was freshly exposed by the cutting of the waves, but for a considerable period of years this cutting has been prevented by the northward extension of the Siasconset apron beach. The face of the bluff at Sankaty Head is now thickly covered with talus, composed of the drift material above the fossiliferous beds, and is in places overgrown with bunches of beach grass. (Plate IV.)

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[1] This chapter has already been published in part in *Jour. of Geol.*, Vol. XIII, No. 8, November-December, 1905, pp. 713–734, under the title: "The Pleistocene Formations of Sankaty Head, Nantucket."

RECENT WORK

During the summer of 1904 the writer made extensive excavations at this point, and exposed a section from the small dunes at the foot of the bluff to a point several feet above the fossiliferous beds. This work revealed features differing somewhat from those previously recorded, and resulted in the discovery of a number of species which have not heretofore been reported from this point. This paper presents the results of this work, and an interpretation of the phenomena observed.

The lower yellowish brown clay reported by Messrs. Desor and Cabot, and later by Mr. Scudder, as occupying a position at the base of the section, was not found, but it has not been noticed by any observer since Mr. Scudder's investigations; and its disappearance is no doubt due to its high dip to the southwest, which, joined with the cutting back of the bluff, has caused it to sink below the level of the dune and beach sands, and thus be beyond reach of the ordinary means of excavation.

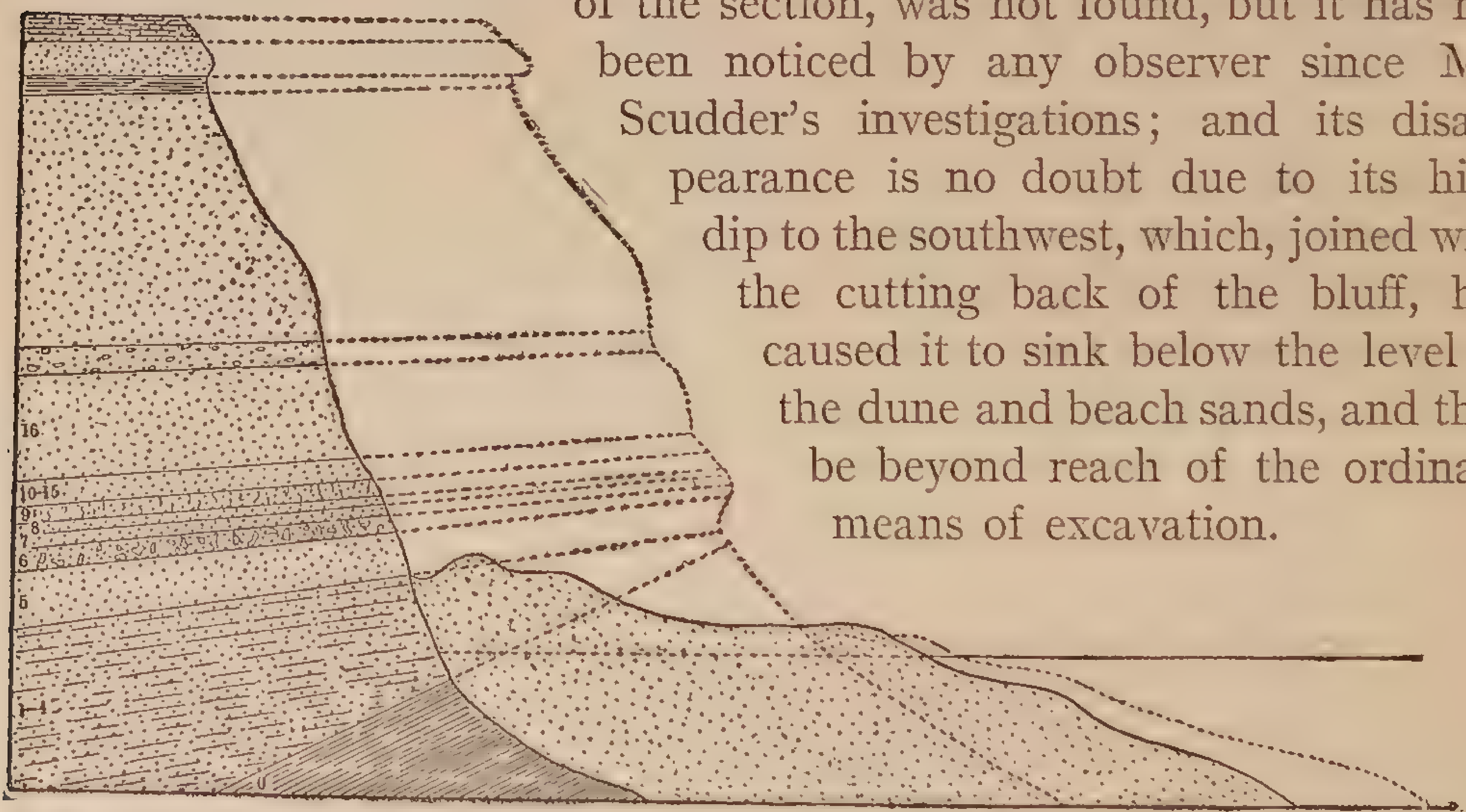
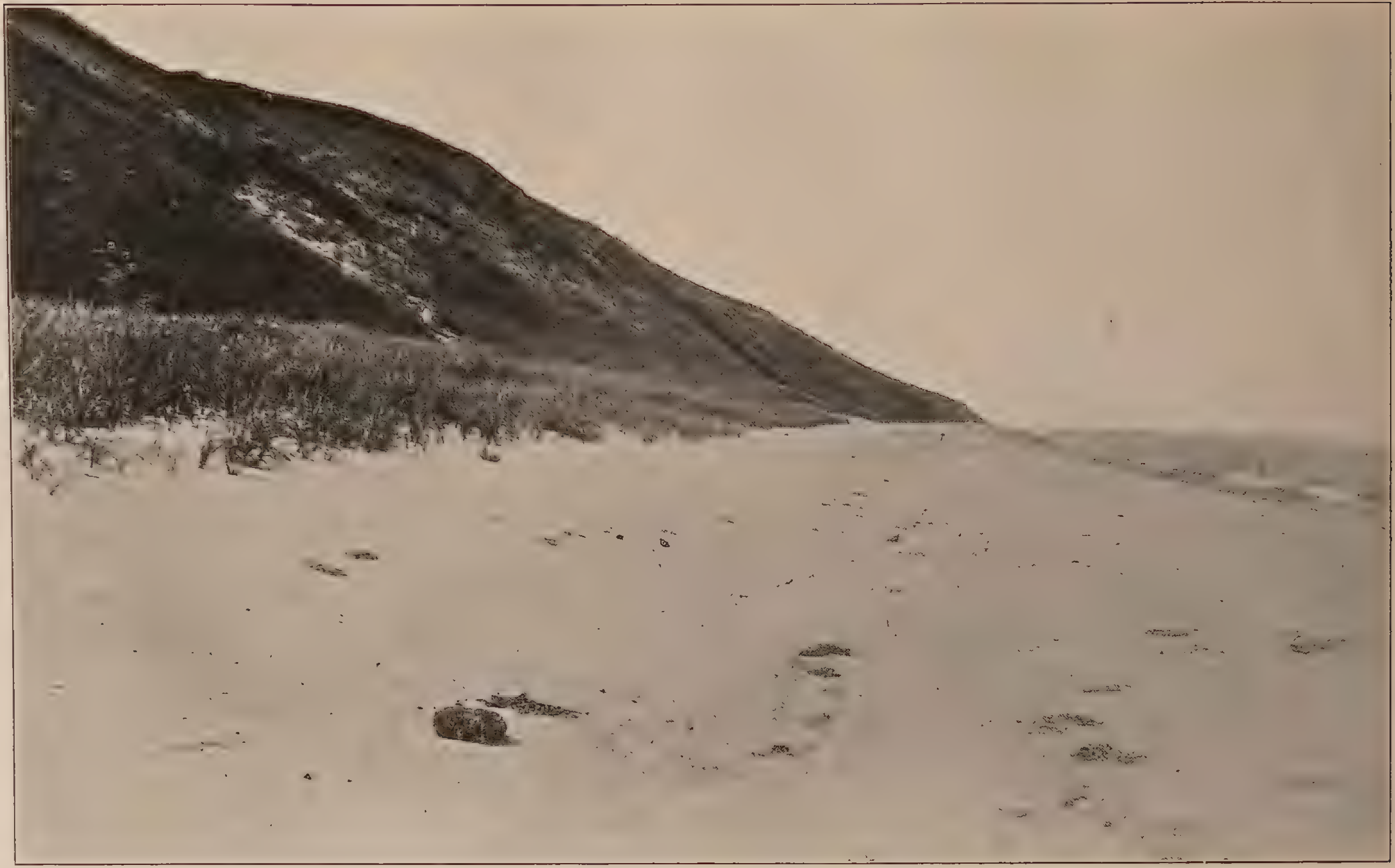


FIG. 2.

Figure 2 shows the effect of the cutting on the position of this lower clay. The dotted lines indicate the eroded portion, with the clay occupying the position as first reported, while the solid lines represent the bluff approximately as it is to-day, with the clay hypothetically many feet beneath the dune sands, and perhaps even below sea-level.

This clay has yielded no fossils, and the descriptions of it agree very well with the clays of undoubted glacial origin, which occur elsewhere on the island. In view of the fact that there is no evidence to the contrary, there seems to be much reason for regarding this lower clay as identical with the pre-Wisconsin till already mentioned.

PLATE IV.



Sankaty Head, looking Northwest.

The fossiliferous beds with their basal stratified sands and gravels which overlie the clay, apparently unconformably, are then interglacial in age, being overlain by the later drift, and the nature of the contained fauna supports this view.

There are indications also which seem to show that similar fossiliferous deposits occupying similar positions occur elsewhere on the island.

From what will be shown farther on, it will be noticed that the outcrops of the old clay are in a more or less east and west line near the head of the apron-plain. The clay is seen to disappear under the overwash of the apron-plain toward the south, so that at a certain distance they must reach a level, which was below that of the sea before the advance of the Wisconsin ice-sheet, and any deposits then laid down would be buried beneath the apron-plain. We have probably then buried beneath this plain an old pre-Wisconsin or interglacial shore line, which extends in a more or less east and west direction, but with considerable irregularities and reëntrant angles or bays, due to the diversity of this old land surface. Borings for a well many years ago at the Kimball farms southeast of the town are reported to have revealed the presence of shells at a depth of fifty feet. This boring was made in the apron-plain about in a position where the old shore line might be expected to be found, and other borings along this belt would very probably produce similar results.

The fossiliferous deposits of Sankaty Head, resting as they do on the old clay, and buried beneath the Wisconsin drift, are in my opinion the exposure of the eastern end of this old shore line.

No attempt was made to expose the section above the fossiliferous beds which constitute two-thirds or more of the bluff; but as previous investigators have found this to consist of the stratified sands and gravels normal to drift deposits, study was concentrated on the beds from the base of the bluff to the top of the fossiliferous deposits, and especially on the latter.

LOCATION

These Sankaty Head deposits have often proved somewhat difficult to locate on account of the depth of talus which now covers the face of the bluff. Professor F. J. H. Merrill reports them (Merrill,'95–96, p. 11) as occurring "at a point about three hundred yards south of the lighthouse," and Dr. Arthur Hollick refers to their position as "about a quarter of a mile south" of that structure. It is possible that they extend for some distance along the bluff, appearing at lower and lower levels toward the south, on account of the dip.

The section[1] exposed by the writer was found to be roughly 375 yards south of the lighthouse tower, measured along the top of the bluff. The section is shown in Fig. 3, and described below.

DESCRIPTION OF BEDS

No. 1. — Light gray sand; coarse and fine, more or less stratified and sorted, with light-colored, clayey seams ½ inch thick, which are somewhat ferruginous and hard. The coarse sand grains are rounded, the smaller are more angular and appear fresher. Small pebbles occur, mostly quartz, up to 10 mm.

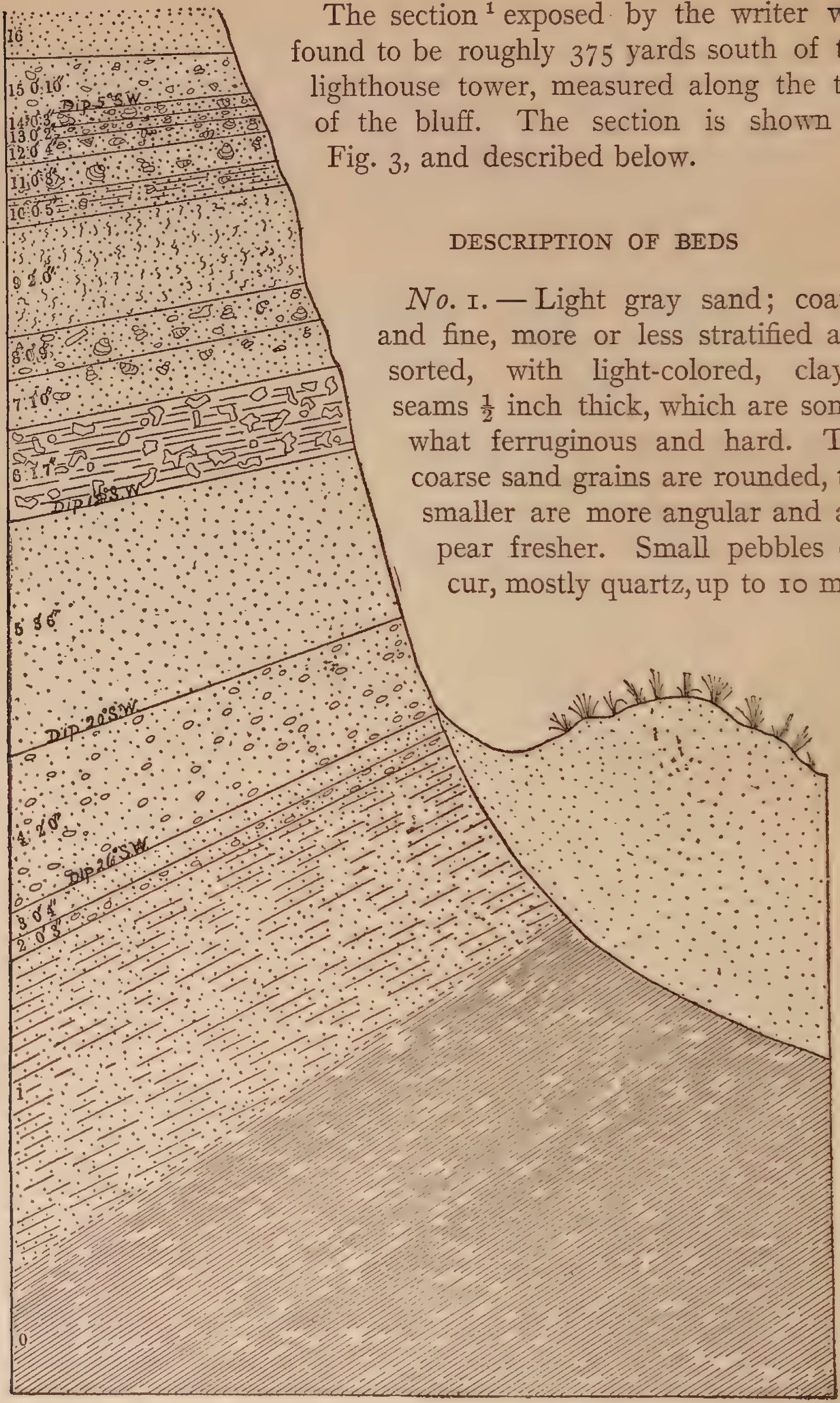


FIG. 3.

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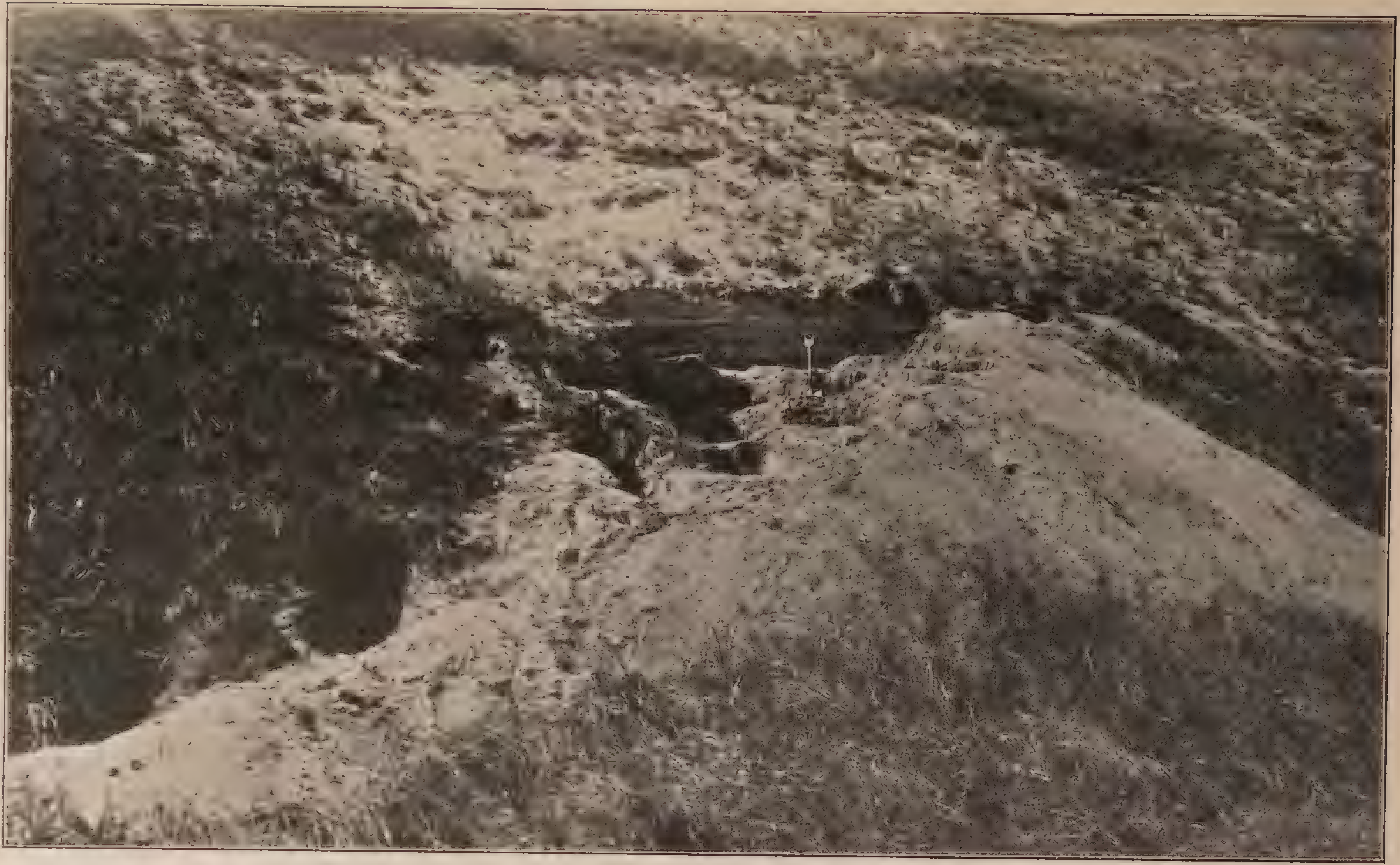
[1] The fossiliferous beds were located in advance by Miss Elizabeth S. Kite.

PLATE V.



THE FOSSIL BEDS AT SANKATY HEAD.
Showing excavations made by the author.

(rarely 20 mm.), which are sometimes incrusted with sand grains cemented by iron oxide.

No. 2. — Ferruginous gravel; sand grains varying in size as in the lower bed, the larger rounded, the smaller transparent and mostly angular; some rounded, and most coated with the oxide of iron; mixed with them are small grains of hornblende and magnetite; contains coarse rounded quartz and other pebbles up to 8 cm. In an excavation which was made through the talus 3 or 4 feet south from this point, this 3-inch bed was found to be 1 foot thick, with a base of hard, clayey sand, streaked with reddish brown and blue clay.

No. 3. — Size of quartz grains uniform with minute grains of hornblende and magnetite. Quartz grains mostly angular, and transparent, ranging up to 3 mm.; no pebbles; color slightly yellowish.

No. 4. — Ferruginous gravel; coarse and fine sand, and pebbles of quartz and other material up to 25 mm., rarely larger; sand and pebbles frequently cemented by iron oxide; pebbles and coarse sand grains well rounded; finest grains of sand angular and transparent; streaks of sand without iron ore are common throughout the bed; grains moderately worn, and quite transparent; larger grains show considerable grinding; black specks throughout, and small pebbles up to 15 mm. occasionally; light gray and pink grains, the latter garnets, the former probably epidote; material evidently derived from disintegrated granite; minute fragments of shells found.

No. 5. — Almost pure quartz sand, grains varying moderately in size, the smaller angular and transparent, the larger rounded and ground; occasional grains up to 8 mm.; small black grains, and also dark green grains of glaucónite; occasional garnet fragments, but no pebbles; a few streaks are ferruginated; top of bed, sand fine and angular, with numerous black specks. The upper surface shows giant ripple marks in places. Lignite was found in the upper part, some in fine laminæ; one stem-like piece, 20 mm. in diameter.

No. 6. — Begins with a very fine, lutaceous sand, with mica scales and quartz grains, a rock flour with no clay odor. Higher up is blue clay, not very sticky, with faint clay odor, containing much quartz flour; pockets of ferruginous sand, which suggest decayed ferruginous concretions; one concretion found, consisting of a hard, reddish brown shell, containing coarse ferruginous sand, and small pebbles. This structure is shown in Fig. 4.

No. 7. — Highly ferruginous quartz sand, occasional pebbles, and irregular fragments from the underlying bed. Quartz grains small, mostly rounded, and opaque by iron deposit; minute shell fragments.

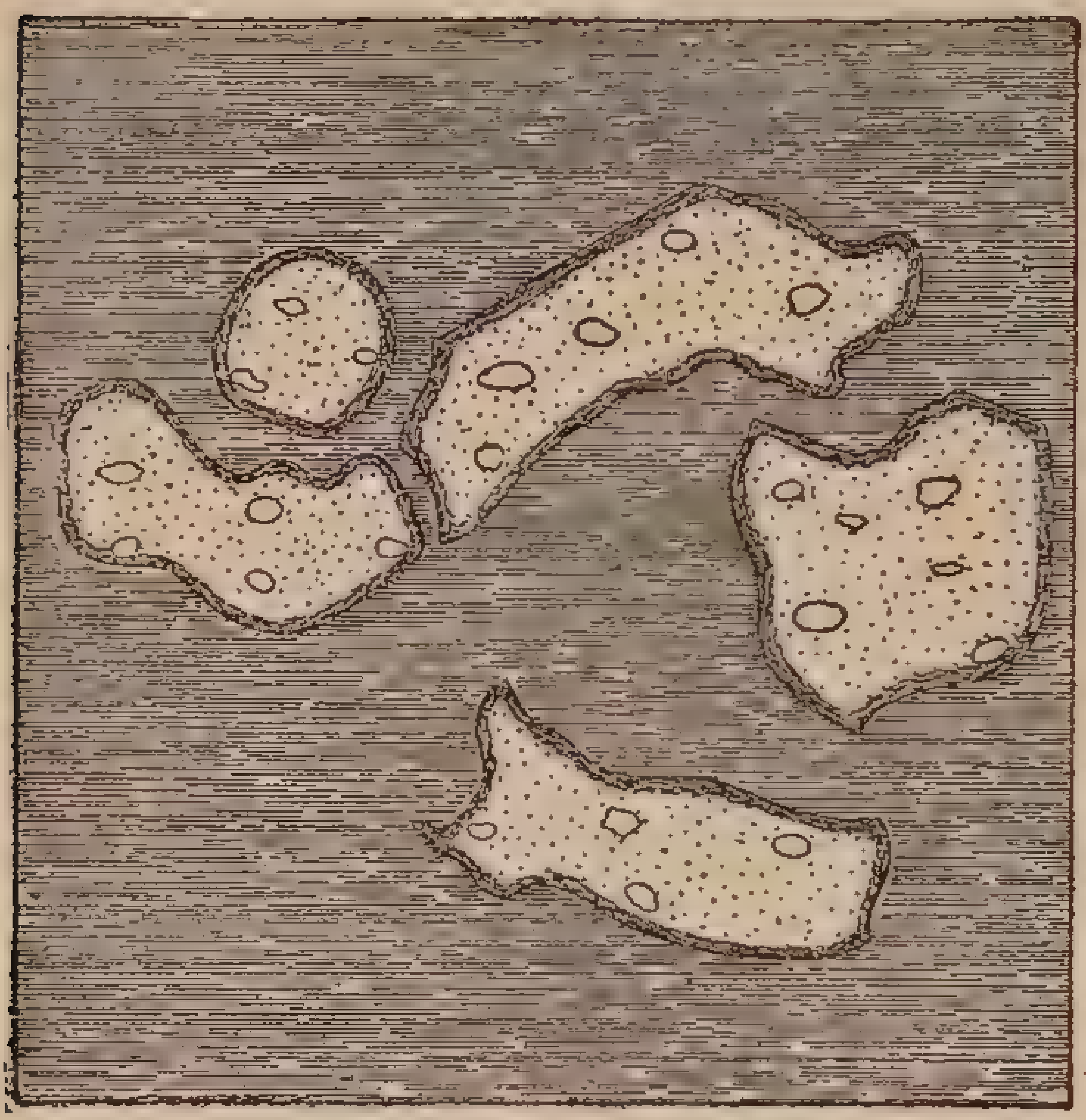


FIG. 4.

No. 8. — Sand of beach type, coarse and fine, the coarse rounded and opaque, the fine angular and transparent, rounded quartz and other pebbles up to 25 mm. *Ostrea* extremely abundant, commonly with the valves still together, unworn and unbroken, and with barnacles still adhering to them; *Petricola pholadiformis*, with valves together and erect; *Venus mercenaria*, with valves in contact and held together by the ligament; *Mya arenaria*, with valves together and erect; *Ilyanassa*, minute *Odostomia*, and other delicate shells occur, none showing wear. Pebbles, not numerous, commonly rounded, rarely angular; no clay. This is the so-called "oyster bed."

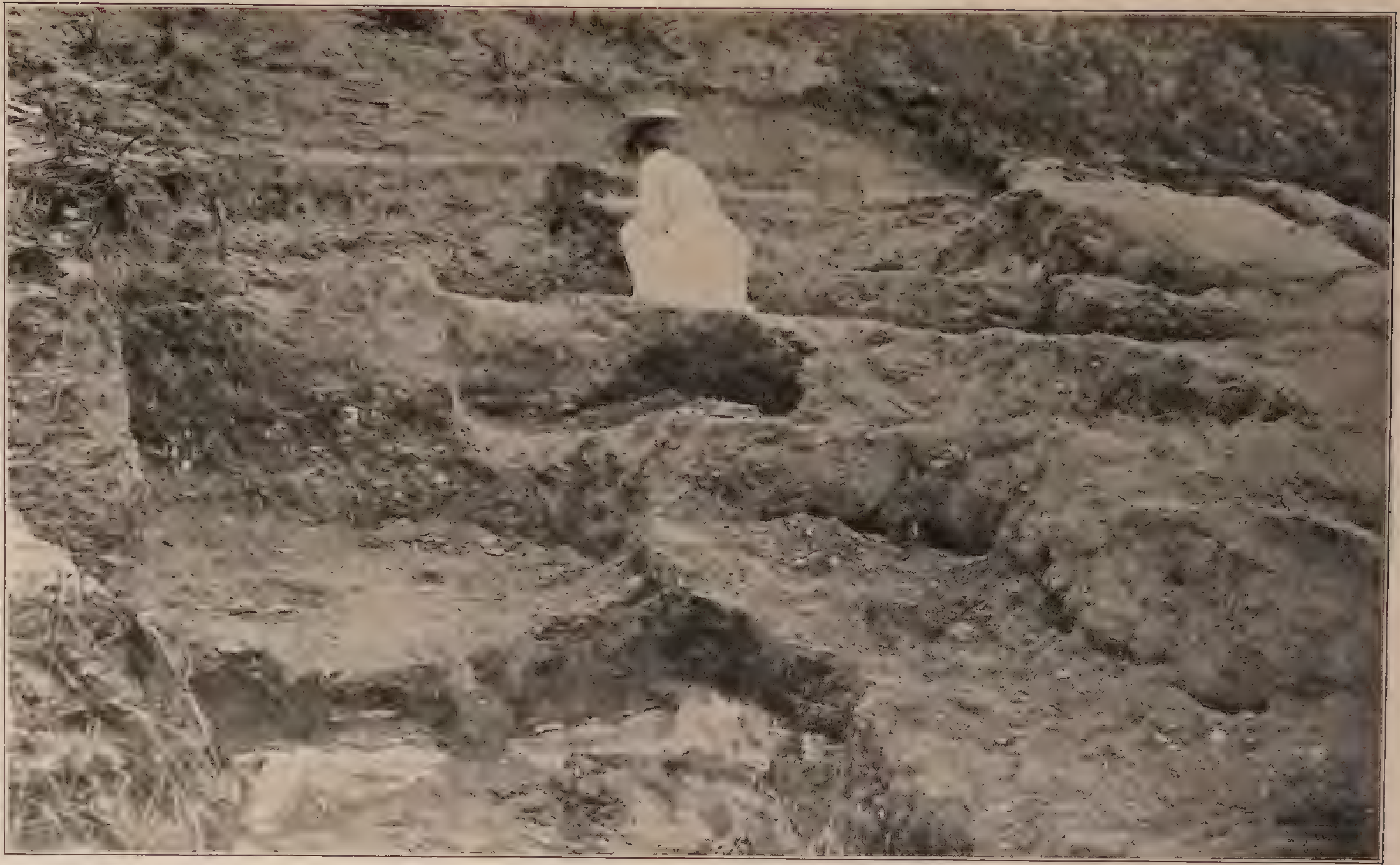
No. 9. — Quartz sand, with ground-up shell material, and often solid masses of *Serpula dianthus*; fine material, largely fine sand, common among the tubes; pebbles, except small ones, not common; no clay or glauconite noticed, but bed hardens on exposure to air. Specimens of *Arca* and *Venus* with perfectly preserved surface markings occur, many of the latter with valves together, and ligament in place. *Solen*, *Mya*, *Cummingia*, and *Ceronia* also occur with valves together, the two former noticed in their natural upright position. A number of other species occur, and some fine shell fragments. Some shells are perforated by borings and the serpulæ sometimes occur in bunches. This bed is generally referred to as the "serpula bed."

No. 10. — Coarse quartz sand, much water-worn and rounded, many of the grains coated with iron oxide. Pebbles up to 8 cm. common, generally well rounded and largely of quartz; also some fine material of lutaceous character. Shell fragments, and occasionally whole shells, mostly *Venus*, found throughout.

No. 11. — Coarse and fine sand, not well assorted. Pebbles angular or sub-angular, 5–6 cm., and even up to 20 cm.; quartz-porphyry quite common. Shells entire and fragmentary, with *Ostrea* and *Venus* very abundant, the latter of the var. *antiqua*.

No. 12. — Quartz sand of varying grain, full of shell fragments and rounded pebbles, generally small, but some up to 15 cm.; shells generally fragmentary, but many delicate ones are perfect. Large *Venus*, and well-preserved *Buccinum undatum*, fairly common; shell

PLATE VI.



A Nearer View of the Fossil Beds at Sankaty Head.

of *Mactra* removed, leaving a large bunch of barnacles in the bed in the position in which they had been attached to it; bed gray, from fragments of *Mytilus.*

No. 13. — Reddish, highly oxidized, ferruginous sand with rounded and sub-angular pebbles up to 8 cm. This is hardly a distinct bed, but is rather a more pebbly and ferruginous layer in Nos. 12 and 14 taken as one bed.

No. 14. — Like No. 12, but more shelly; resembles an uncemented coquina, full of barnacles, in places almost entirely made up of them (*Balanus portatus*); numerous perfect, small shells, and sub-angular pebbles.

No. 15. — Mussel bed; normal beach sand, in places crowded with fragments of *Modiola*, and containing complete small shells of other genera. The mussel shell fragments are generally worn; *Balanus* fragments also common; perfect *Astarte* found, and more or less fragmentary *Lunatia heros*, and *Venus* shells; fossils like those found in Nos. 12, 13, 14, but not so numerous. The upper layer is marked by rounded pebbles, generally small, but occasionally 8 cm. in diameter; pebbles sometimes occur in the mussel layer of lower part of bed. Some of the purer layers of sand are pink, rarely yellow.

No. 16. — Pure quartz sand, of varying grain, stratified and well assorted; grains all rounded and opaque, as if sand had been wind-blown before deposition; some fine streaks, almost like rock-flour, which show as very fine sand grains under microscope, and contain mica scales; occasional small pebbles up to 6 mm.; black specks numerous in the finer streaks; rarely a small shell fragment.

The general appearance of the section toward the latter part of the work is presented in Plates V and VI. A close view of the fossiliferous beds is shown in Plates VII and VIII. No. 8, with the serpula bed above, is shown in Plate VII, while the beds above, including the lower part of the white drift sands, appear in Plate VIII.

The upper beds will be referred to now somewhat more collectively and their more general features described.

No. 10 seems to present some transitorial features from the serpula bed below, while Nos. 11, 12, 13, 14, and 15 have frequently been classed together as the "upper shell bed," although the last has received the special name of the "fragment bed."

In the section exposed, No. 15 seems hardly to be separated as a distinct bed from the bed below, there being no sudden change of character. The shells and shell fragments of No. 14 were found to extend upward into this so-called "fragment bed," in the form of streaks and pockets, appearing less and less in the upper part.

The proportion of shell material to sand in No. 15, as compared with Nos. 12, 13, and 14, taken as one bed, was found to be considerably less. This would be expected in the re-sorting of material, the lighter and more soluble shell material being dissolved and borne away, leaving a greater proportion of sand. No. 15, then, has all the appearance of being a disturbed and partially assorted portion of the "upper shell bed."

In exposing these beds northward along the bluff, it was found that at a distance of 25 or 30 feet from the section, No. 15 pinches out, while the three beds below have become indistinguishable and their combined thickness is only 9 inches. No. 11 also appeared finer and less shelly, and had increased in thickness to 1 foot 6 inches. The most noteworthy fact, however, and that which is responsible for the thinning out of these upper beds, is the unconformity of No. 16, which seems to be the lowermost member of the drift deposits, or its base. So far as the writer knows, this unconformity between the fossiliferous beds and the overlying drift deposits has never before been noticed.

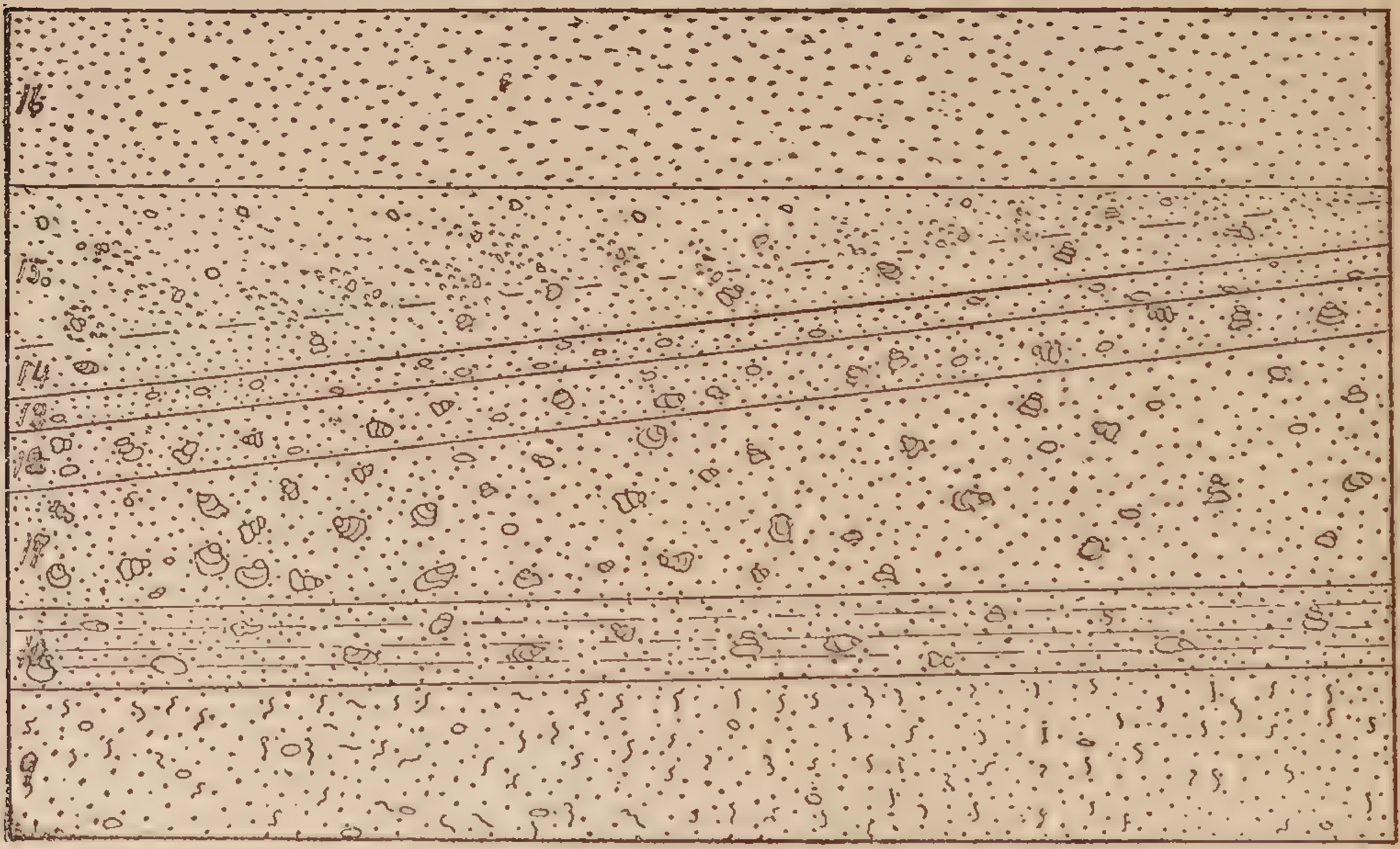


FIG. 5.

The general phenomena presented by these upper beds are shown in Fig. 5, in which the vertical scale is about three times the horizontal. The thinning of the fragment bed and the unconformity between it and the overlying white sands are also shown in Plate VIII.

FOSSILS

Of the total number of species heretofore reported, only eleven were not found, and are given separately in the following list:[1]

Bryozoa.
  Membranipora tenuis Desor.
  M. catenularia Smett.
  Eschara verrucosa Esper.
  Celleporaria incrassata Smith (?).
Pelecypoda.
  Arca pexata Say.
  Gouldia mactracea Linsley.
  Gemma gemma Totten.

Gastropoda.
  Scala greenlandica Perry.
  Eupleura caudata Say.
  Cerithiopsis greenii C. B. Adams.

Crustacea.
  Eupagarus pollicaris Say.

A complete list of the fossils found is given below. A number of species not heretofore reported from this locality were found. It was noticed also that a number of species were not found in the beds in which they have been reported as occurring or are more common in some other bed. The writer is of the opinion that many fossils have formerly been collected from the talus, and referred to the wrong bed; for the irregular face of the section, covered with talus, was found at first to be very confusing, and it was not until considerable work had been done that the real nature of the beds, with their sequence and characteristic fossils, was established. Many of the fossils were collected before the work had proceeded far enough to make it possible to say with certainty what beds they had come from, but, as far as possible, these will be indicated by their corresponding numbers. The species not before reported from these deposits are indicated by an asterisk.

In the table: x = occurs, a = abundant, c = common, r = rare.

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[1] A *Panopeus* has been reported from these beds, but its species not identified.

	Number of Bed				
	8	9	10	11	12–15
Porifera.					
Cliona sulphurea Desor	a	x	x	x	
Echinodermata.					
Strongylocentrotus drobachiensis Müll				x	spines a
Annelida.					
Serpula dianthus Verrill		a	a		
Bryozoa.					
Hippothoa variabilis Leidy	?	a	x	?	x
Pelecypoda.					
Arca ponderosa Say			?		
A. transversa Say	a	a	a	a	
Venus mercenaria Linn	a	a	x	x	x
V. mercenaria var. antiqua Verrill		x	x	a	
Ostrea virginiana Lister	a	c	a	a	a
Anomia aculeata Gmelin					a
A. simplex D'Orb					c
Mya arenaria Linn	c	c	c	c	x
M. truncata Linn					few
Mactra solidissima Chemn			one		few
*_Serripes laperousii_ Deshayes					one
*_Pecten magellanicus_ Conrad					one
Ensis directus Conrad	c	c	c	c	
Corbula contracta Say			c		
Mytilus edulus Linn	x	c	x	x	c
*_M. exustus_ Linn	few	?			
*_Modiola plicatula_ Lamk	?	?	?		
M. modiolus Linn					c
M. hamatus Verrill	c	x	x		
Crenella glandula Totten					c
Macoma fusca Say					few
*_M. fusca var. fragilis_ Say					one
*_M. incongrua_ von Martens					? one
Cummingia tellinoides Conrad	c	c	c	?	
Petricola pholadiformis Linn	r	r	r		
*_Pholas truncata_ Say			one		
*_Zirfaea crispata_ Linn					one
Panopea arctica (Lamk.) Gould (= _Saxicava norvegica_ Linn.)					frag.
Saxicava arctica Linn					c
Pandora gouldiana Dall					r
*_P. crassidens_ Conrad					two valves
Astarte quadrans Gould					a
A. undata Gould					r
A. castanea Say					a

PLATE VII.

Detail of Lower Portion of the Fossil Beds.

	NUMBER OF BED				
	8	9	10	11	12–15
**A. crebricostata* Forbes					*r*
Ceronia deaurata Turton (= *Mesodesma.*)					few
C. arctata Adams					*c*
Venericardia (*Cyclocardia*) *borealis* Conrad					few
V. novangliae Morse					*c*
Thracia truncata Migh. and Adams					few
Gastropoda.					
Odostomia impressa Say	*a*	*x*	?	?	
O. trifida Gould	*a*	*x*	few	few	
Turbonilla interrupta Totten	*r*				
Ilyanassa obsoleta Say		*x*	few		
I. trivittata Say					*c*
Urosalpinx cinerea (Say)	*r*	*c*	*r*	*r*	*r*
**Bittium negrum* Totten	*r*				
Cingula (*Rissoa*) *aculeus* Gould					*r*
*C. *latior* Migh. and Adams					one
**Cerithiopsis terebralis* Adams					one
Skenea planorbis Forbes and Hanley					*r*
Margarita (*Solaricella*) *obscura* Couth					frag.
**M. undulata* Sowerby					one
**Fasciolaria ligata* Migh. and Adams					one
Tritonofusus stimpsoni Mörch					*c*
**Fusus tornatus* Gould					frag.
**Chrysodomus stonei* Pilsby					one
Buccinum undatum Linn					*c*
**Sipho islandicus?* Linn					frag.
Trophon scalariformis? Gould					*r*
Lunatia heros Say					*c*
L. triseriata Say					*c*
Neverita duplicata Say					one
**Littorina palliata* Gould					one
Astyris lunata Dall				*c*	
Caecum pulchellum Stimpson					*r*
Diodora noachina Gray					*r*
Crucibulum striatum Say					*r*
Crepidula fornicata Lambk	*c*	*a*	*c*	*c*	
C. convexa Say	*c*	*c*	*c*	*x*	
C. plana Say	*c*	*c*	*c*	?	?
Crustacea.					
Balanus crenatus Brug					*c*
B. eburneus Gould	*c*	*c*	*c*		
B. porcatus Da Costa					*a*
**Eupanopeus herbsti* Milne-Edwards		*a*			one worn claw
**Neopanope texana sayi* Smith		*c*			
**Callinectes sapidus* Rathbun		one claw			

It will be noticed that twenty-one species new to this locality were collected. Of these a number were identified by Dr. W. H. Dall. The crab fragments were identified by Miss Mary J. Rathbun. The identification of *Serripes laperousii* Deshayes, *Macoma incongrua* von Martens, and *Pandora crassidens* Conrad, was a surprise, as the first two belong to the arctic fauna of the Pacific coast, and, according to Dall, have not heretofore been found east of Point Barrow, while the last is common in the Miocene of Maryland, and, according to the same authority, has not previously been found above that horizon. It does not seem possible that the *Pandora* could have been derived from an older bed, as all the other species are distinctly Pleistocene; and in case the material from an older bed had been disturbed and redeposited, we should expect to find a number of associated species. Moreover, the two left valves found were entirely free from any trace of an old matrix, were no more worn than the other fossils from the same bed, and were of the same color and general appearance. It would seem, then, that *Pandora crassidens* Conrad has in some localities continued on into Pleistocene times. The two Pacific species would seem to indicate that in Pleistocene times the "Northwest Passage" was more open than at present, and perhaps also that in the interglacial period in which these beds were deposited the ice had entirely disappeared from even the northern part of the continent, so as to leave the channels along the coasts of that region free from ground ice.

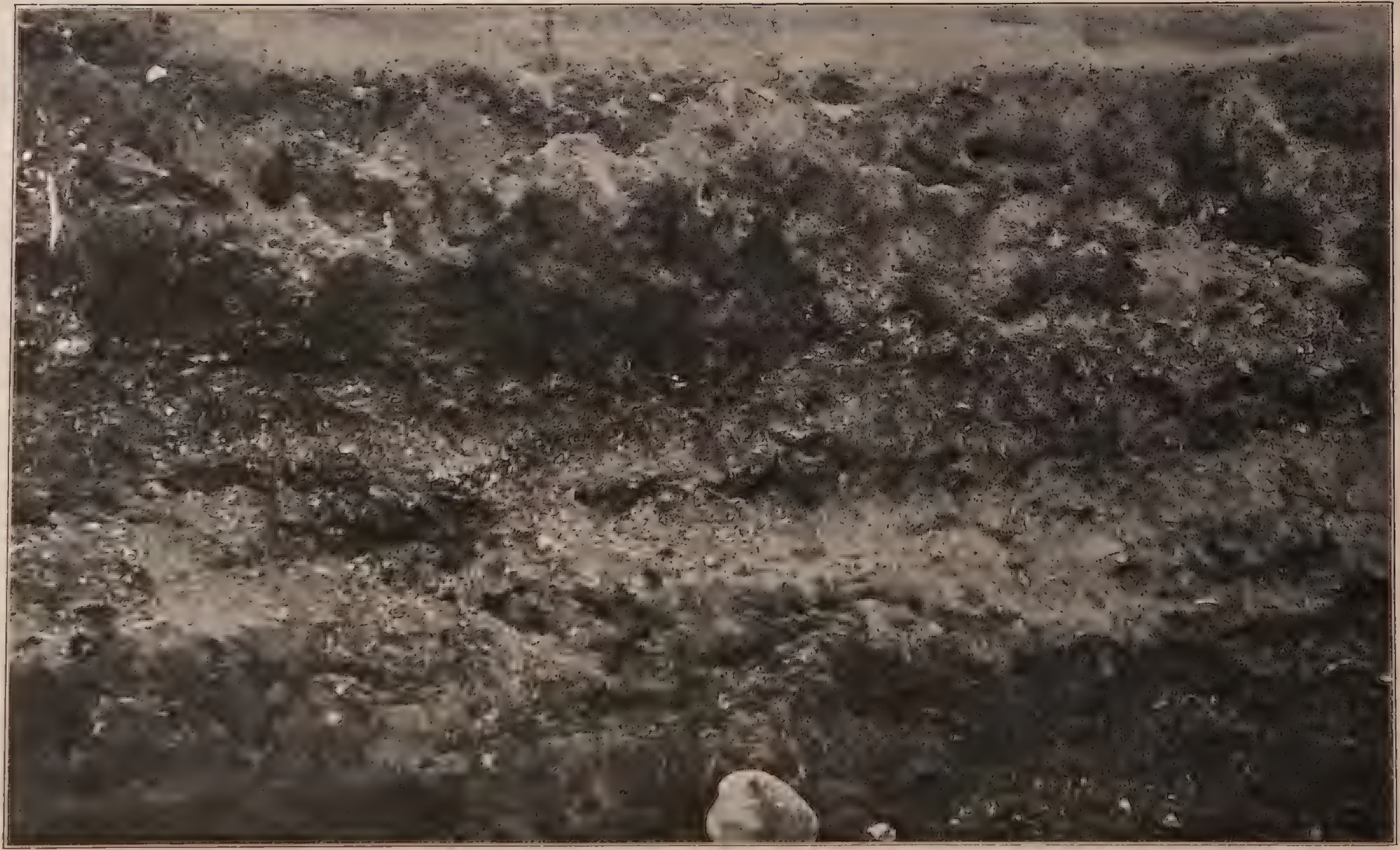
A single specimen of the rare species *Chrysodomus stonei* Pilsby was found, which was first reported and described from specimens washed ashore from supposed Pleistocene beds under the sea, off the southern coast of New Jersey. This and the Miocene *Pandora* are the only species yet found occurring in these beds which are now extinct.

It has been a matter of comment, that not a single *Pecten* has heretofore been found at this locality in beds furnishing in abundance such species as *Ostrea virginiana*, *Venus mercenaria*, and *Mya arenaria*. In looking over a quantity of material from the "upper shell bed," a two-inch shell fragment was found which seems to be clearly identified as from near the ventral margin of a specimen of our northern species, *Pecten magellanicus* Conrad.

Modiola hamatus Verrill is mentioned in former reports as common in the "lower shell bed," and was found in association with *Mytilus exustus* Linn, from which at times it is difficult to distinguish. It is probable that the latter species has been mistaken for *Modiola hamatus* by collectors from this locality, and all listed under the latter name.

In regard to the position in the section of *Venus mercenaria var. antiqua* Verrill, previous reports mention it as abundant in the "lower

PLATE VIII.



Detail of Upper Portion of the Fossil Beds.

shell bed," but not found above this horizon. The writer found, on the contrary, that the most typical forms occurred only above the serpula bed, in No. 11, while forms less typical, and more intermediate between it and the common species, were found in the serpula bed. In this case, the name *antiqua* would be somewhat of a misnomer, as the variety would seem to represent simply a short-lived mutation from the common species.

The *Astartes* as a group are very variable, presenting some puzzling differences within what may be considered a single species. Several species occur in the Sankaty deposits, and a small form which occurs very abundantly in the upper beds (over two hundred being collected) seems to have been identified in the past as *Astarte quadrans* Gould; but of the great number collected, the one which approaches nearest to *A. quadrans* of Gould seems to be identical with the variety *portlandica* of Mighels, the others differing from *A. quadrans* in a line of development far beyond even *A. portlandica.*

A number of the Sankaty Head forms are shown in Fig. 6, Nos. 6–15, while several *A. castanea* from the same locality are figured in Nos. 1–5

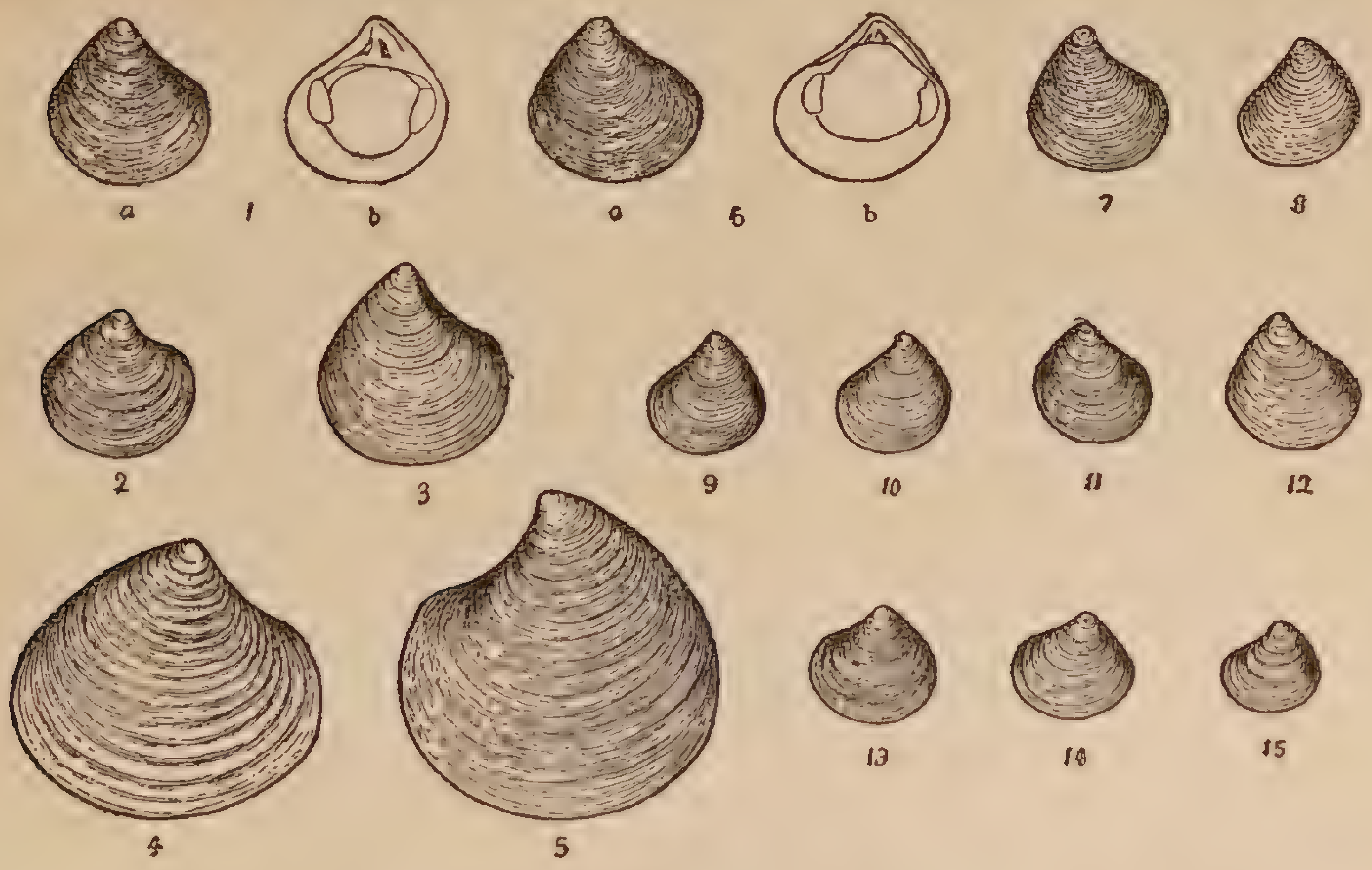


FIG. 6.

for comparison. The whole series of *A. quadrans* differs from *A. castanea* in their small size, excentric position of the beaks, the nearly straight anterio-dorsal margin, the absence of the broad, slightly elevated bands of growth sometimes found in *A. castanea*, and the fact that the latter has a much heavier shell, with very much higher hinge area and stronger teeth.

In the figures shown, No. 14 is almost identical with Gould's figure of *A. portlandica*, and is considered here as representing the type of that species. Most of the other forms figured, however, seem to show specific differences, being much higher and having the beaks much more excentrically situated, and should perhaps be separated as a distinct species, for which the name *sankatyensis* is proposed.

Nos. 7–12 exhibit very well this great divergence from the type of *A. portlandica*, while Nos. 6, 13, and 15 are intermediate types.

A. portlandica at the present time is more limited in its range than *A. quadrans*, and is somewhat rare.

From the fact that *A. sankatyensis* occurs only in the "upper shell bed," where it is quite common and associated with arctic species, it seems probable that it has a very northern range, or is a form which has died out, and is not represented among recent shells.

INTERPRETATION

It has been thought that these fossiliferous beds at Sankaty Head were made up of old material redeposited; that the last or Wisconsin ice-sheet, moving across the sea-floor, had torn up and transported a quantity of material from old beds lying beneath the sea, and redeposited it in the present position near the ice-margin. A notable case of this kind is found in the deposits containing marine fossils which are found on the flanks of Mount Snowdon in Wales, and which owe their elevated situation to the movement of the great Irish Sea glacier over the bed of that sea, and the crowding of its front with its morainal accumulations up on to the highlands of northwestern Wales.

It may be mentioned in this connection that the line of kame hills of which Sankaty Head is the eastern extension do not represent the southern limit of the ice-sheet at this point. It was found that the ice maintained a quite stationary front some three miles farther to the south, forming the well-developed contact slope which runs in a northwesterly direction from Tom Never's Head.

I held the same opinion in regard to these Sankaty Head deposits at the beginning of the work, the beds at that time presenting a very confused appearance, which was found later to be due to a superficial disturbance with a mingling of talus. When the disturbed portion was finally removed, however, the beds were found to present very characteristic and constant characters. That these beds could not owe their origin to glacial action, but are normal marine deposits, seems to be certain for the following reasons: (1) Numerous delicate, perfect, and unworn shells occur. (2) Numerous bivalves, already mentioned in the description of the beds, were found in the natural position in which they lived, with both valves together, and, in the case of *Venus*, with even the ligament in place. (3) There is no mixture of faunas, as would be the case in the redeposition of material from different beds. The three lower beds contain fossils which have a distinctly southern range, and are of a shallow water type; while the upper beds contain a decidedly northern fauna, many species being characteristic of arctic seas, and of considerably deeper water. Such conditions can hardly be explained except by supposing these beds to be in their original positions.

In view of the phenomena observed, and the facts ascertained in regard to these deposits, it would seem that an attempt might be made toward an explanation of their history. The lower clay noticed by early observers is probably identical with the yellowish brown clay found elsewhere on the island, generally more or less covered by the glacial drift. This clay is apparently an old till of pre-Wisconsin age, and which, modified by erosion, formed the land surface of hills and valleys in this region before the advance of the last ice-sheet, which buried it under a heterogeneous mass of drift. At this time shallow inlets probably occupied some of the low areas between the higher land surfaces, or lagoon-like bays were to be found at points along this old shore, protected from the open sea by bars or low barrier beaches.

The Sankaty Head deposits seem to be best accounted for as having accumulated in one of these inlets or lagoons. The lower beds were undoubtedly deposited in a shallow body of water connected with, but well protected from, the open sea. This is well shown by the prevalence of such species as *Ostrea*, *Venus*, and *Mya*, and especially numerous specimens of mud crabs, and the presence of our edible crab, *Callinectes sapidus* Rathbun, which is found to-day in some of the little creeks connected with the harbor on the north side of the island.

Although the total thickness of the fossiliferous beds is but eight feet, a great difference is found between the lower and upper beds, showing changes in the physical conditions. At the time of deposition of the upper beds, the waters had become much colder, probably due to the return of glacial conditions, the fossils being chiefly of the northern fauna driven southward in front of the advancing ice-sheet. The fossils, besides being more northern, and in some instances even arctic, in their range, are also of species which are generally found in somewhat deeper water.

A noticeable unconformity is found between the fossiliferous beds and the overlying ten feet of white sand (No. 16) at the point where the section was exposed, as shown in Fig. 5. These sands are very pure, and are finely stratified and assorted, the bedding being nearly horizontal.

The sand grains are mostly well-rounded and worn, and at rare intervals minute fragments of shells occur. In fact this bed, to all appearances, seems to consist of wind-blown sand derived from dunes which have been destroyed and redeposited.

It will be noticed also from the general section, Fig. 3, that there has been a gradual decrease of dip from the lowest of the beds exposed, to the uppermost of the fossiliferous beds, above which the unconformity occurs.

The upper fossiliferous beds, with their change of fauna, the apparent unconformity above, and the overlying white sands, show changes in the physical conditions which require special explanation.

There seem to be but two hypotheses which are at all applicable to the facts, and while the phenomena can hardly be reconciled to one, it will be given first, and the points wherein it fails to satisfy the conditions will be explained. The first hypothesis may be stated as follows:

After the lower beds were deposited and the Wisconsin ice-sheet had attained considerable extension, the land began to subside as the ice advanced, while a deeper water fauna, of arctic type, driven southward by the advancing ice, lived in the region, and its shells were embedded in the upper beds. As the ice reached Nantucket, the pressure of its front against obstructing surfaces produced a crumpling or folding of the strata, as has been observed in other regions, such as shown in Fig. 7. This folding would account for the gradual increase of dip from the top to the bottom of the section at the point indicated by the diagonal line *AB*, representing the face of the bluff in Fig. 7. After the folding had taken place, the barrier beach, brought below sea-level by the subsidence of the region, was destroyed by wave-action and redeposited as the upper white sands. As the Wisconsin ice-sheet reached and passed beyond this point, it is likely that a portion of these sands was removed; but soon deposition of glacial material began to take place, and these beds were buried under the vast amount of kame sands and gravel which form the upper part of the bluff.

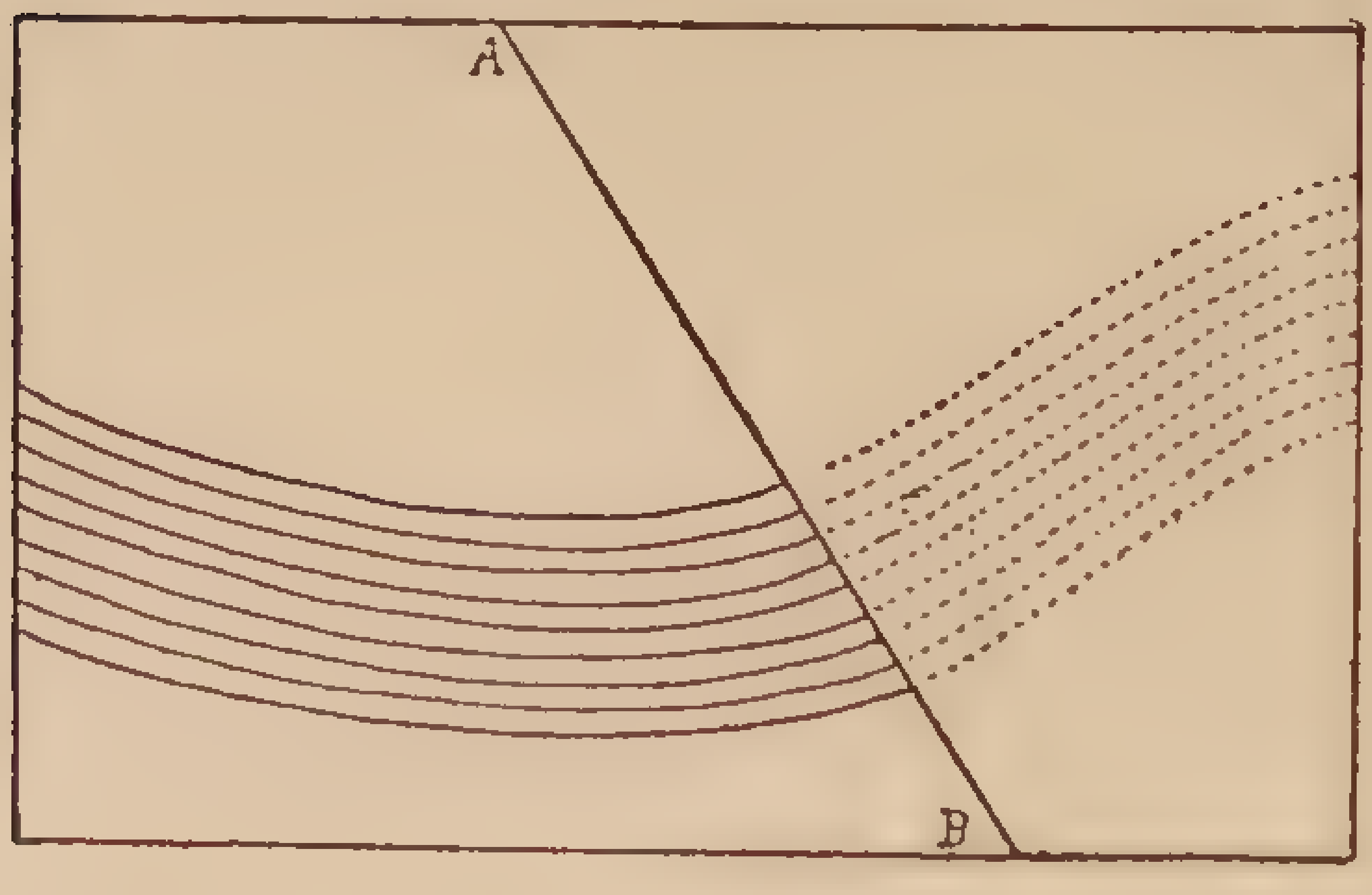
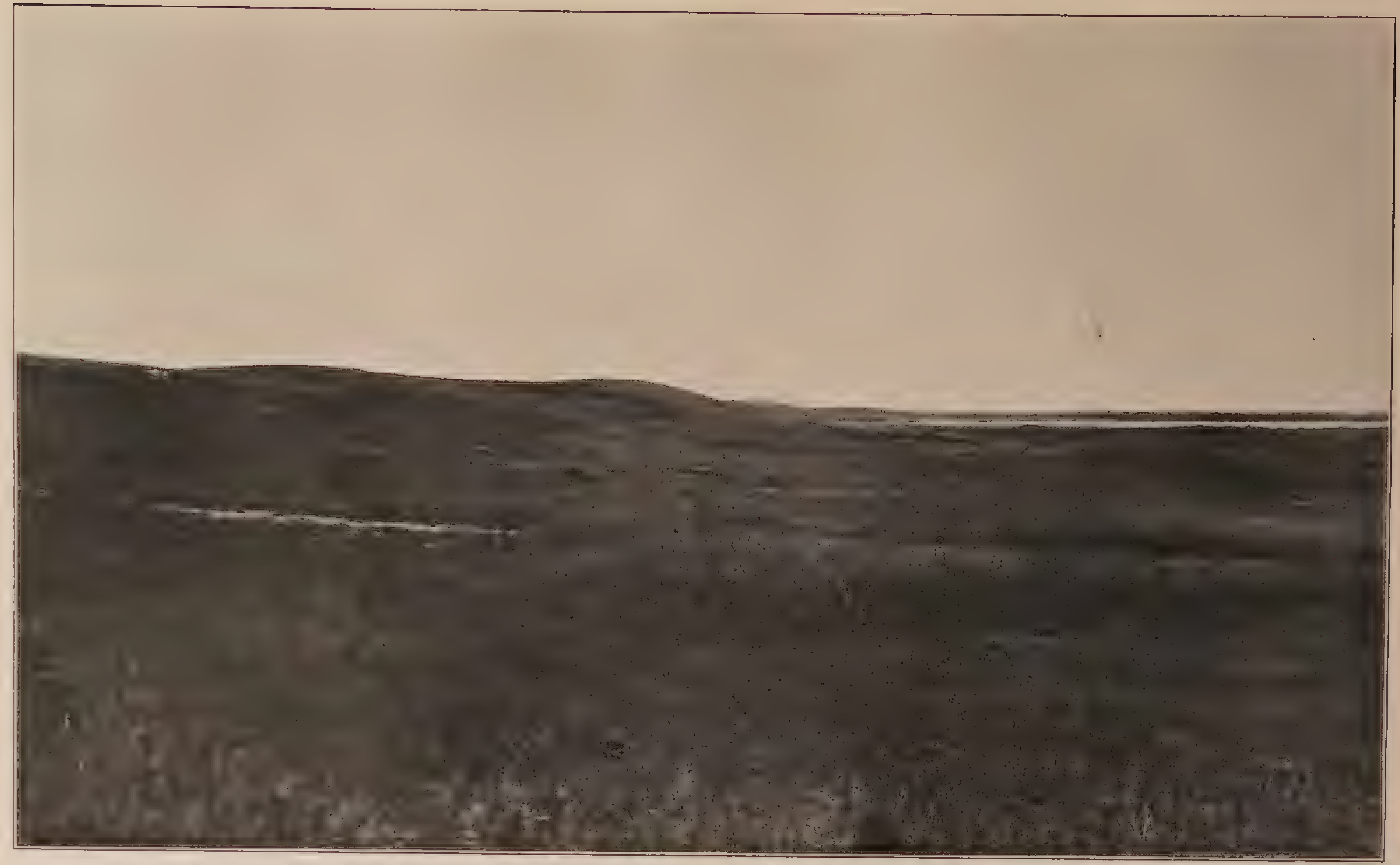


FIG. 7.

This hypothesis seems to fail in the following particulars: (1) It seems improbable that the difference in dip can be accounted for in the way mentioned, because (*a*) the earliest reports on the dip of the various beds agree almost exactly with present observations, while a cutting back of the bluff, such as has taken place since the locality was

PLATE IX.



Gibb's Pond and Saul's Hills, looking East.

first visited, should show a very different dip for the same beds, as will be seen from a study of Fig. 7; and (*b*) the lateral pressure sufficient to produce this folding would be indicated by minor crumplings of the tough upper clay (No. 6), but, so far as observed, these crumplings do not occur. (2) In order to produce the folding, we must assume the ice-front to have been in the immediate vicinity, which assumption cannot be reconciled with the deposition of the upper white sands, which are of seaward origin, very pure, and unmixed with any such heterogeneous material as could not fail to be present in proximity to the ice-front.

This theory, then, in its entirety, cannot be reconciled to the facts, and must be modified in some particulars.

The following hypothesis is presented as being in accord with all the phenomena observed, and probably coming nearest to the truth in an exposition of the history of these deposits: —

At the beginning of this deposition, a precipitous shore probably stood to the north of the lagoon, or the lagoon itself may have been in the nature of a basin-shaped inlet, open to the south, and surrounded by steep shores of which the deeply dipping lower clay formed the portion below sea-level. A variety of material, derived from this old shore by the encroaching sea before the outer bar was formed, was spread over the bottom of the basin, assuming nearly the dip of the surface upon which it was deposited, the dip becoming less and less as the basin became filled. This agrees with the coarse nature of the lower deposits and the irregular bedding noticed. One of the lower ferruginous gravels (No. 2) was found to increase from 3 inches to 1 foot in thickness within a distance of 3 or 4 feet to the south. The dip is in the nature of a false dip, the deposits resembling very much in structure those fanlike non-marine accumulations in which the dip decreases in passing upward through the successive layers. We may consider then that the dip is an initial one, and not caused by a subsequent folding of the strata.

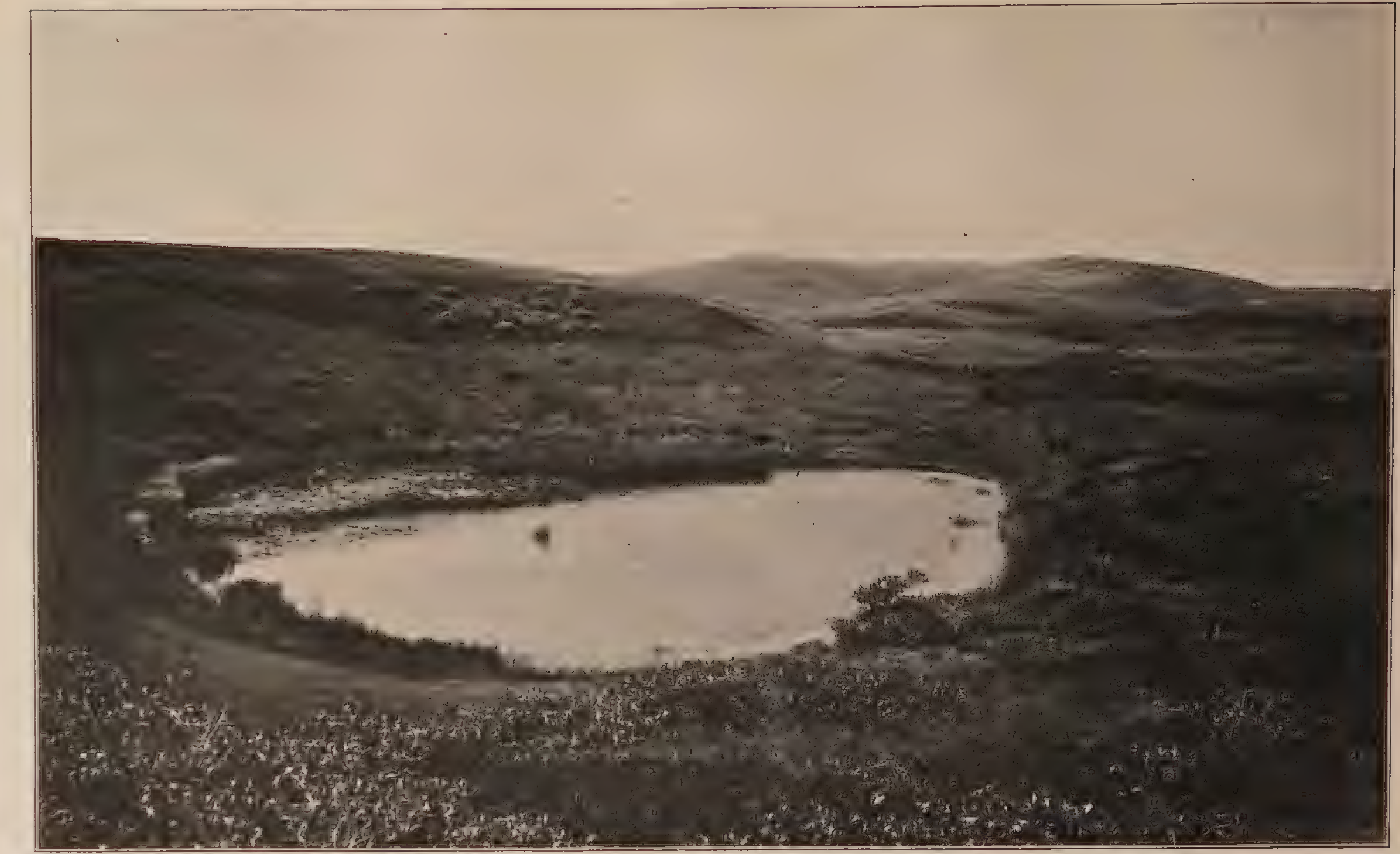
The lower white sands (No. 5) probably represent the washing in of some seaward material, and giant ripple marks, such as would be made by ocean waves, were found on the upper part. The lignite found in this bed is no doubt derived from seaweed and driftwood.

The lagoon or inlet now became well protected from the open sea by the development of the outer bar or barrier beach, and the upper clay of No. 6 became deposited from landward washings, on the floor of the lagoon. This now became the home of shoal-water animals, as evidenced by the species which have already been enumerated. How long these conditions lasted it is of course impossible to tell, but they were brought to an end before the deposition of the upper beds. As these upper beds were formed, a subsidence of the land in this region was taking place, and no doubt connected with the advance of the huge mass of the Wisconsin ice-sheet. The water became colder, the southern fauna was driven out, and deeper-water, northern, and even arctic species were present, and included in the deposits. As the subsidence continued, the barrier beach, unable to hold its own, allowed the seas to break into the lagoon, causing a disturbance of the upper deposits, the formation of the fragment bed, and the unconformity. Finally this outer bar became destroyed, and the material of which it was composed was washed into the lagoon, forming the upper white sand (No. 16).

The next event which took place was the advance of the Wisconsin ice-sheet over and beyond this region, eventually burying the deposits under 50 feet or more of drift. This last advance of the great continental glacier may have pushed its front some distance to the south of Nantucket, during which time, and during its retreat to the position in which the Nantucket terminal moraine was formed, or during the first part of this Nantucket stage, a reëlevation of the land to its present position must have taken place.

At any rate, from evidence gathered all over the island, we know that the land stood not far from its present level when the ice-front occupied the Nantucket position. There is absolutely no evidence to show that the Nantucket moraine, with its apron-plain and other characters, was formed below sea-level, or at any elevation essentially different from that which it occupies at the present day.

PLATE X.



Wigwam Pond and Saul's Hills, looking Southwest.

CHAPTER V

THE WISCONSIN ICE-SHEET ON NANTUCKET

THE phenomena presented by the typical accumulations at margin of an ice-sheet are of four kinds, or may be divided into four zones, — the kame hills, the fosse, the ice-contact slope, and the apron-plain (Fig. 8).

1. Kames are deposits formed at or near the margin of the ice as the result of the deposition of the load of a subglacial stream through diminution of velocity. As the stream flowed under a certain pressure, the relief of this near the ice-margin would result in decrease of velocity, with a deposition of the load carried. They are composed of sands and gravels more or less stratified, showing the action of running water as well as of ice. Kames are also probably formed at times at some distance back from the ice-front, when from any cause, such as the presence of caverns or hollows under the ice, the velocity is decreased and the load deposited. They are sometimes arranged in belts simulating true terminal moraines, and giving rise to the name kame moraine. These kame ridges may be covered with boulders left by the final melting of the ice, be pitted with kettles and covered by steep hillocks, giving rise to the knob and basin topography of a true terminal moraine.

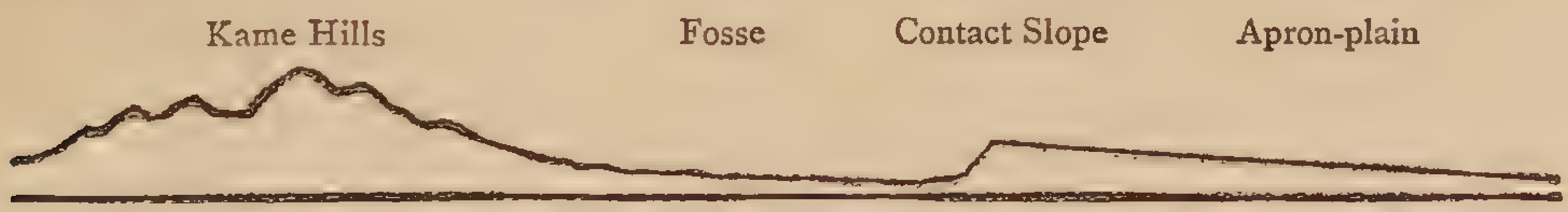


FIG. 8.

The kame deposits on Nantucket seem to have been formed some distance back from the actual ice-front, and form a belt of hills which may be referred to as the kame hills.

2. The fosse is the low area or ditch, as the name implies, between the kame hills and the ice-contact slope, supposed to have resulted from the presence of the marginal ice.

3. The ice-contact slope is the slope rising from the fosse at the head of the apron-plain. Here the ice-front rested as the apron-plain developed in front from the overwash, and this slope thus marks the actual front of the ice at any point.

4. The apron-plain is the one formed in front of the ice-margin

by the overwash material brought by streams coming from the glacier. It slopes gently away from the top of the ice-contact slope, and is traversed by shallow valleys or creases formed by the glacial streams as the plain developed.

From one cause or another, all of these features are not always developed, but they are strikingly shown on the island of Nantucket, especially the eastern half, where the older topography does not enter as a disturbing element. These four features will now be traced across the island, and any peculiarities which they present will be discussed. The presence of the old till as a pre-Wisconsin topography will be noticed in the same connection wherever it rises to such an elevation as to prevent the normal development of these four features. It is the presence of this old topography interfering with this normal development which has heretofore proved so puzzling in tracing everywhere on the island the exact limits of the ice-margin as shown by the contact slope.

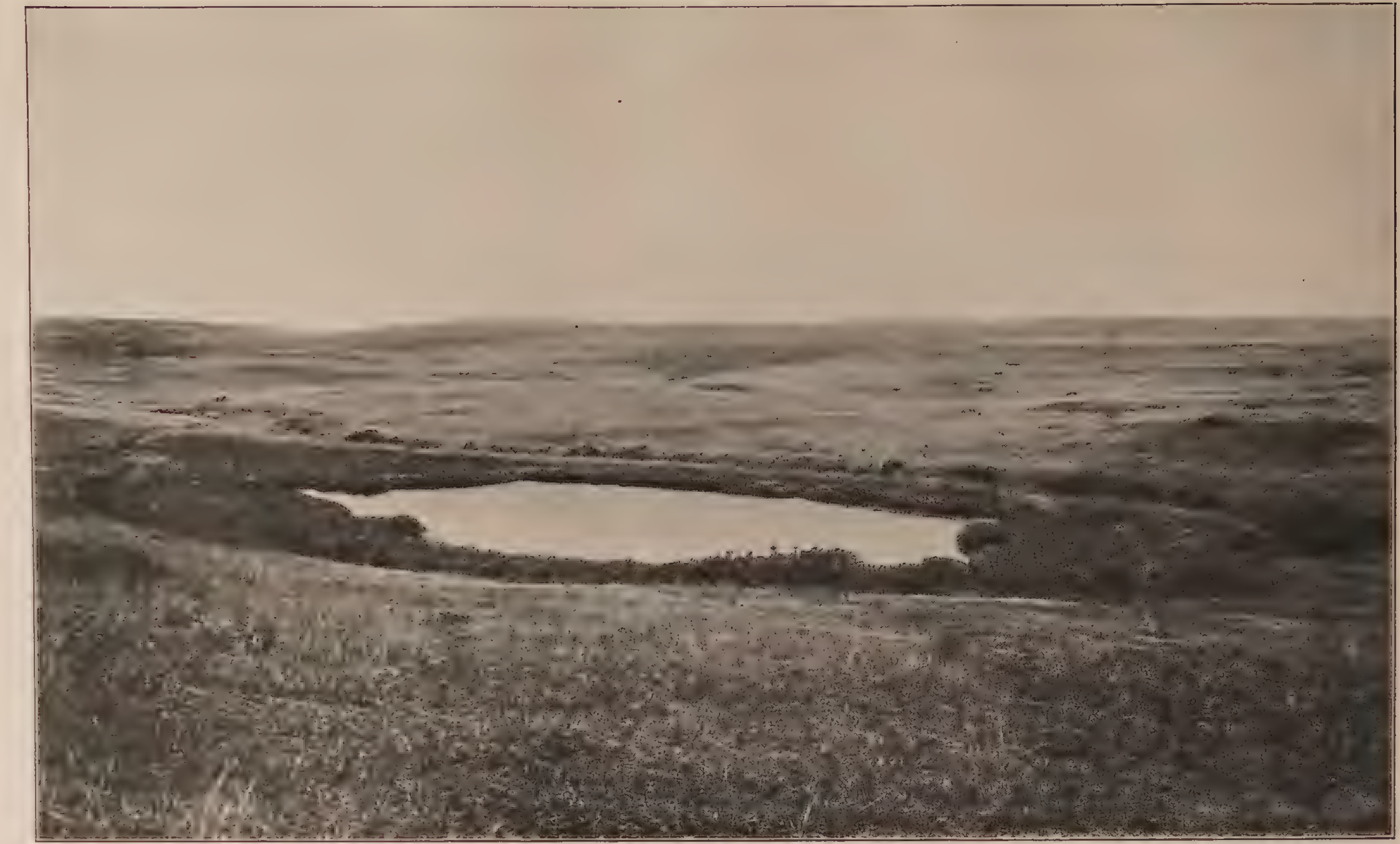
THE KAME HILLS

The kame hills, which on Nantucket form the backbone of the island, and the highest elevations are distributed in a belt having an approximate east and west direction, and when more or less separated into groups by lower levels in the chain, have been given such local names as Saul's Hills, Shawkemo Hills, and Trott's Hills (Plate IX). These hills owe their elevation in part to the presence of the old till beneath, but as a whole show a normal development with the fine knob and basin topography characteristic of a kame moraine. Many of the basins or kettles are occupied by picturesque sheets of water, which constitute the small circular ponds of the island.

These ponds are generally small, and are of course distributed, with few exceptions, throughout this belt of kame hills (Plates X and XI).

At the eastern extremity of the island, the cutting back of the sea across this belt has produced the high bluffs at Sankaty Head. This chain of hills extends the whole length of the island, with the exception of the neighborhood of the town. Just east of the town, Nantucket Harbor occupies a break in the belt, and this depression where the kame hills should normally occur is probably due, in part at least, to a great trough in the underlying clay, which here sinks so low as to be unable to support the morainal material above sea-level, and which has since been modified and partially removed by waves and tidal currents.

The deepest part of the harbor is about 36 feet, close to Brant Point, and just inside of Coatue Point a depth of 25 feet is reached, while most other parts of the harbor are quite shoal.



Pout Pond and Shawkemo Hills, looking Northeast.

This irregular sea floor is due not only to the presence of sand-bars and ridges, but in great measure to the irregular surface of the old clay. One proof of this is the former presence of several large boulders, so near the surface of the water between Pimny's Point and Coatue that they were a menace to the navigation of small boats plying up and down the harbor, and were recently removed.

These boulders must have rested on the hard clay surface, as loose sands in the presence of strong tidal currents would have been unable to have long maintained them in their position so near the surface.

On the bar is a depth of but 8 or 9 feet at mean low water, and the expensive government jetties have been only partially successful in deepening the channel on account of the presence of the hard, compact clay. The superficial sands were soon removed by the sweep of the tidal currents between the jetties, revealing the clay beneath, which on account of its compact nature offers a stubborn resistance to the deepening action of these currents. Similar but greater depressions no doubt account for the breaks in the moraine between Nantucket and Martha's Vineyard.

This belt of kame hills was formerly thought to mark the extreme limit of the ice-front, and was believed to be a terminal moraine such as that forming the "backbone" of Cape Cod, and that on the high land on the western part of Martha's Vineyard. All the region to the south was supposed to be of the nature of an overwash or apron-plain. More recent investigations have, however, shown that this is not the case, and that this kame moraine was formed beneath the ice at some distance back from the actual front (Woodworth, '97, 1, p. 90). The ice reached in some places to a considerable distance farther south; in the eastern extremity of the island, to a distance of nearly two miles beyond the front of the kame hills, and the fosse and ice-contact slope can be traced throughout almost the whole length of the island. These are features which are much less conspicuous than the kame hills, and have often escaped notice. It is in relation to these also that the pre-Wisconsin topography enters more as a disturbing element.

THE FOSSE

The fosse is the irregular belt or zone lying between the kame hills and the contact slope. It is generally depressed and free from any great amount of glacial material. On this account we should expect it to represent more nearly the old land surface in this region, before the advent of the Wisconsin ice, and this is found to be the case. As the fosse is the low area between the kame hills and the contact slope, it will not be further discussed here, but only in connection with the tracing across the island of the contact slope.

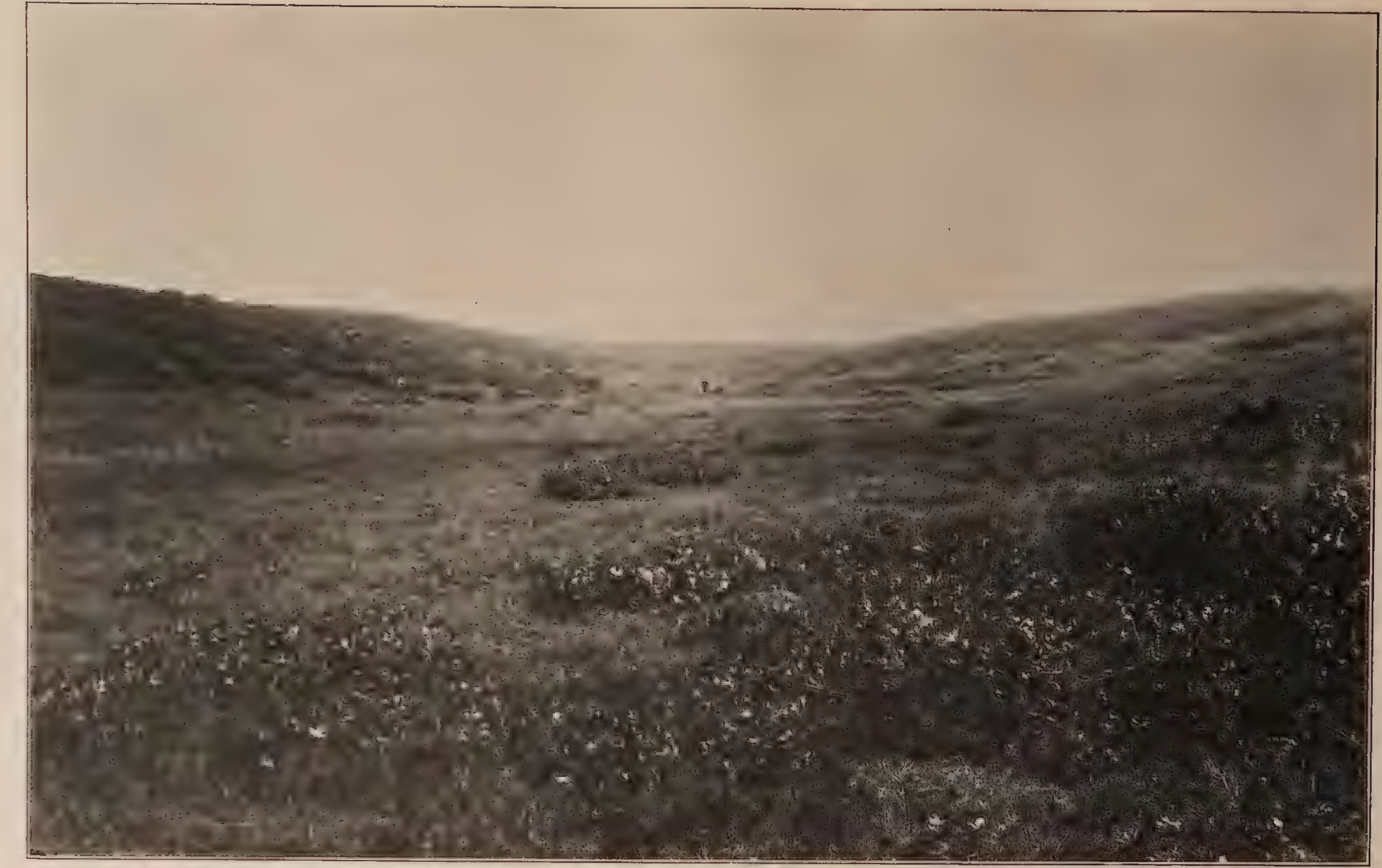
THE ICE-CONTACT SLOPE (Woodworth, '89)

Beginning with the eastern extremity of Nantucket south of Sankaty Head, a low area not many feet above sea-level is found between the village of Siasconset and Tom Never's Head. This is the eastern end of the fosse. Its southern boundary is a steep cuesta-like face running in a southeasterly direction from a point just south of Gibb's Pond, and terminating at the present time in the promontory of Tom Never's Head. This is the ice-contact slope, and marks the extreme limit of the ice at this point. The island has of course been cut back by the sea and formerly extended much farther to the east and south, when this slope was prolonged to the southeast with perhaps varying direction for an unknown distance At the top of this slope, produced by the contact of the ice with the overwash material, is a level plain sloping gently to the southwest, and traversed by shallow valleys or creases heading in the highest part of the plain at the top of the contact slope. This plain is the eastern part of the apron-plain, which forms the whole southern region of the island south of the contact slope, and is made up of the wash coming from the glacier front. The contact slope here is the best developed on the island, and its regular and horizontal sky-line sixty feet above the fosse in front, as seen from the neighborhood of Siasconset or Saul's Hills, is truly impressive. Its termination in Tom Never's Head marks the most southeasterly point reached by the Wisconsin ice-sheet on the present land surface in North America. With portions of its extension westward, it is probably as fine an example of an apron-plain and contact slope as is to be found anywhere.

From the point south of Gibb's Pond, the fosse narrows, the contact slope being much farther north, and the kame hills extending south to meet it. Farther to the west, it widens again into an undulating prairie-like expanse, until within a short distance of Barnard's Valley. Here a tongue-like extension of the Shawkemo Hills almost reaches the contact slope, leaving the fosse as a deep and narrow east and west valley (Plate XII), appearing like the upper part of the crease known as Barnard's Valley, with which it is continuous, although somewhat deeper. This later valley with Madequecham farther east cut deeply through the contact slope and were outlets for the subglacial waters.

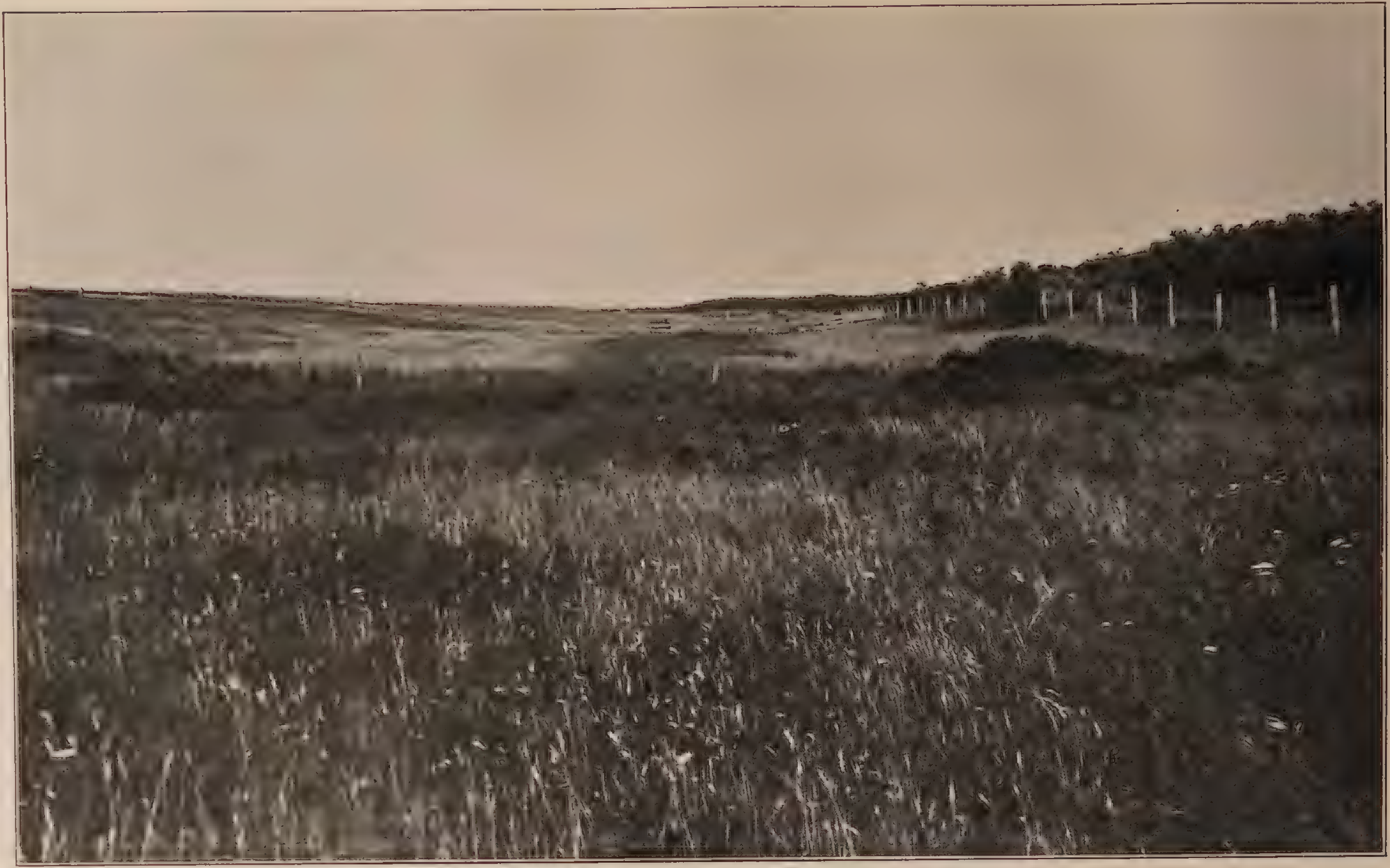
From Barnard's Valley, the fosse widens again, and the contact slope runs northwest for about half a mile, until it crosses the Polpis road, where it sweeps around to the southwest to the so-called state road.

PLATE XII.



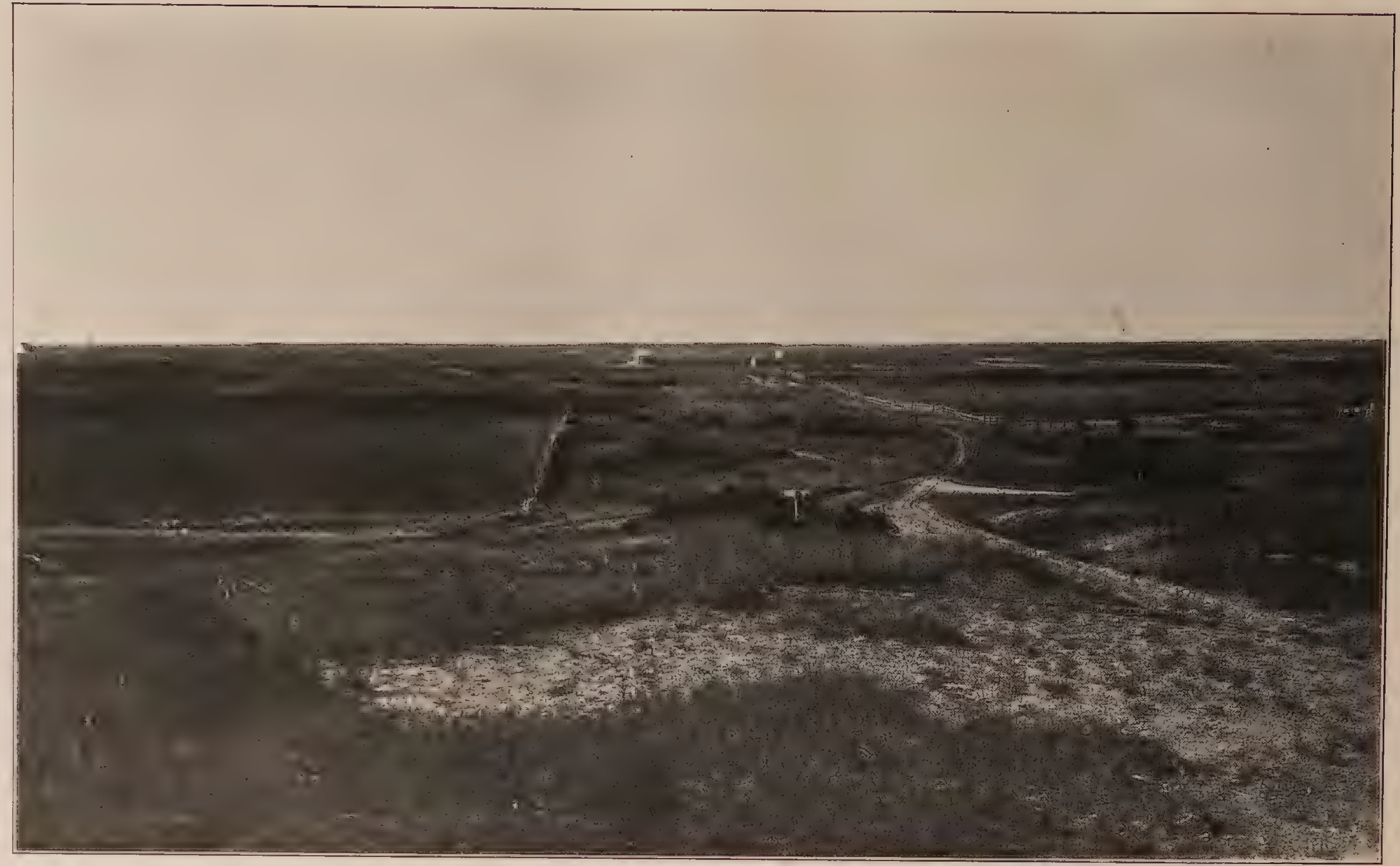
A Narrow Portion of the Fosse, Upper Part of Barnard's Valley, looking East.
Contact slope on the right.

PLATE XIII.



Miacomet Valley, a Crease in the Apron-plain, looking Northeast.

PLATE XIV.



THE APRON-PLAIN FROM MILL HILL, LOOKING SOUTH.

From this point it disappears as a traceable feature for a short distance, appearing again in the neighborhood of Mill Hill.

On the high ridge of Mill Hill it is again well developed, and can be traced with the fosse continuously to the western end of the island. This break of about a mile in length occurs in the same position as the break mentioned in the kame hills; that is, it occurs just south of the harbor in the depression in which is found the trough of Miacomet Valley (Plate XIII). This valley exhibits some peculiar features, and will be discussed later on with any facts or theories relative to the position of the ice-front at this point.

On Mill Hill the contact slope occupies quite an elevated position, the town lying in the fosse, which at this point is on rather high land, which attains an elevation of about 40 feet above sea-level. Its elevation here is the result of the old till rising to this height, so that the contact slope and moraine are built upon a pre-Wisconsin hill. Excavations in the town reveal this clay, and its presence is further indicated by the fact that the apron-plain is not built up to the top of the slope as elsewhere on the island, so that the moraine appears as an east and west ridge between the contact slope on the north, and a less abrupt and more irregular slope on the south. It is of the same nature as the Cape Cod moraine and the one on the western part of Martha's Vineyard, and very much resembles the kame hills. The apron-plain at this point is not fully developed for some distance to the south of the morainal ridge, but appears as an undulating surface, alternating between low swells of sand and gravel, and more level stretches of clayey soil with swampy hollows (Plate XIV).

These features are the result of streams from the ice-front laden with overwash material. They swept down upon the old clay surface, eroded here, and deposited there a portion of their load. The presence of the old till practically at the surface at the head of the apron-plain is easily detected. At the western end of the town also, by New Lane, this till appears on the surface, and is worked by the town for use on the roads.

Westward of Mill Hill, the ridge is continued by what are known as the Popsquatchet Hills and John Wing's Hill. The fosse sinks to near sea-level, and forms the green bottom land between these hills and the "Cliff," which extends from the Lily Pond to the north head of Hummock Pond. On account of its low level and clayey soil, it presents a very fertile appearance, and is diversified by a number of small rush-bordered kettle ponds.

The contact slope now begins to turn towards the southwest, and farther on forms the eastern side of the long valley of Hummock Pond (Plate XV), to within half a mile of the south shore, where it turns at right angles and runs in a northwest direction to beyond the head of Clark's Cove.

The fosse corresponding to this part of the contact slope presents the most peculiar features of any place on the island. Between the arms of Hummock Pond is a quite high, isolated, drumloid hill, from the summit of which a commanding view is obtained of the western part of the island. It has been somewhat puzzling, and its north slope has been mistaken for the ice-contact slope. It is, however, a hill of the old pre-Wisconsin till clay, and is nearly bare of drift material, with the exception of boulders, which are numerous, especially on its southern flanks. It was overridden by the ice, and stands really in the fosse, which it divides here into two parts. The northern portion of the fosse is quite extensive, and extends as Trott's Swamp up to the kame hills of the same name to the north. The other part appears as the trough of Hummock Pond from the "Narrows" to a point three-fourths of a mile south of the "Bridge," with the low swampy ground to the south of the hill known as George Easton's Swamp. South of George Easton's Swamp is a small but well-formed apron-plain, constituting the peninsula between the arms of Hummock Pond, and traversed by a crease which, entering Clark's Cove, forms the small cove between Little Ram and Great Ram Pasture Points. The ice-contact here appears as a low slope between the head of the apron-plain and the swamp. No boulders were found south of this slope, while they are large and abundant immediately to the north. The drumloid hill thus stands in the fosse in the angle formed by the change in direction of the ice-margin from southwest to northwest.

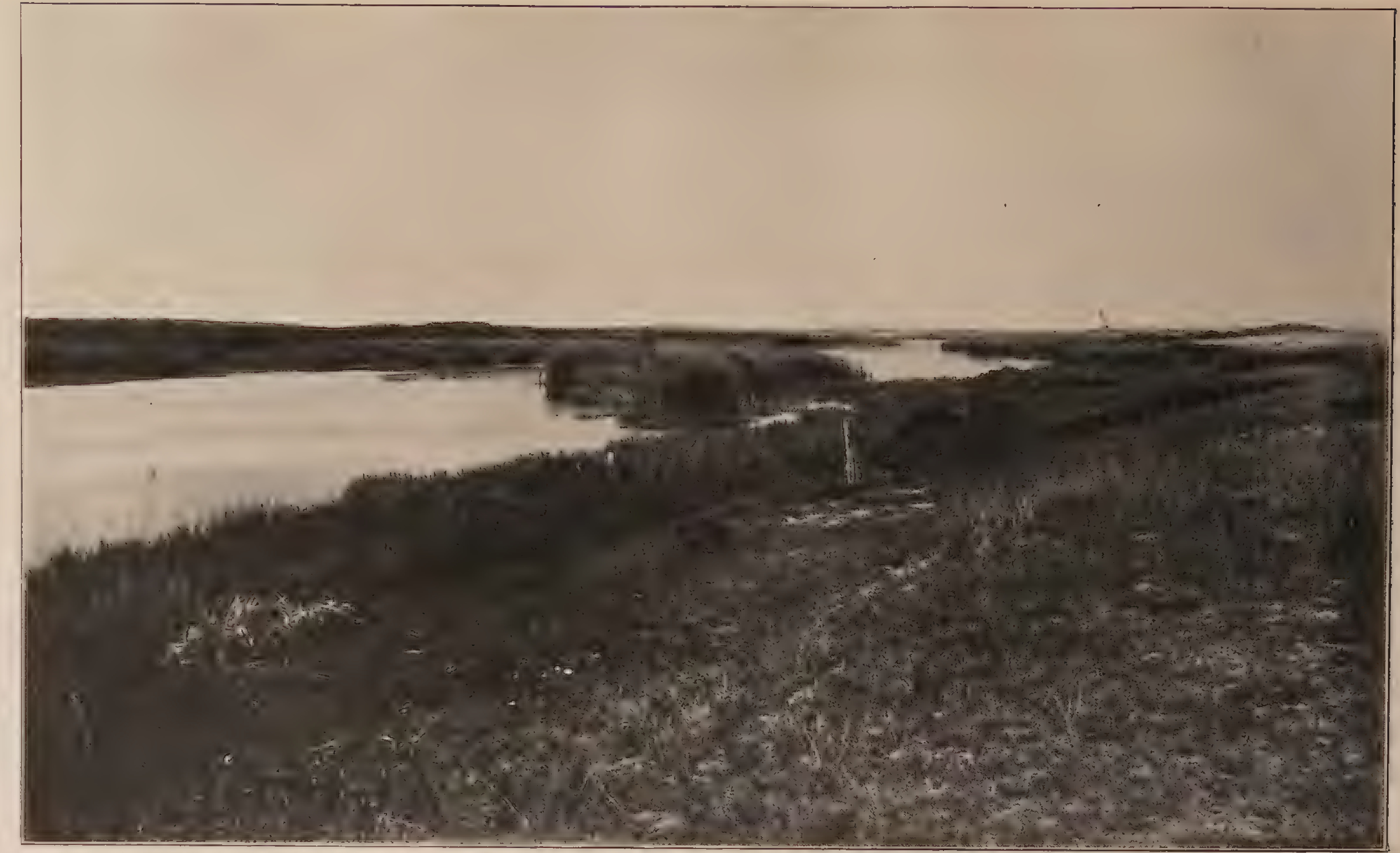
From the head of Clark's Cove, for the distance of about one-half mile, the contact slope is indefinite and obscure, but beyond becomes plainer, and runs almost due west to Massasoit Bridge on Long Pond, where it is well defined (Plate XVI). The pond is embayed in the fosse to the north of this contact slope, and its very narrow, straight, and canal-like shape to the south is due to the restriction produced by the apron-plain through which it breaks (Plate XVII).

From Massasoit Bridge, the contact line turns abruptly and runs northeasterly for half a mile as the west bank of the pond to a point opposite Jeremy's Cove, at which point it again turns abruptly, and running westerly for nearly a mile, is lost in the shifting sands of Maddequet Harbor, to reappear on the northern part of Tuckernuck Island.

The fosse from Trott's Swamp to Long Pond is represented by the low-lying land to the south of Trott's Hills, and has a clayey soil and is diversified by numerous swamps.

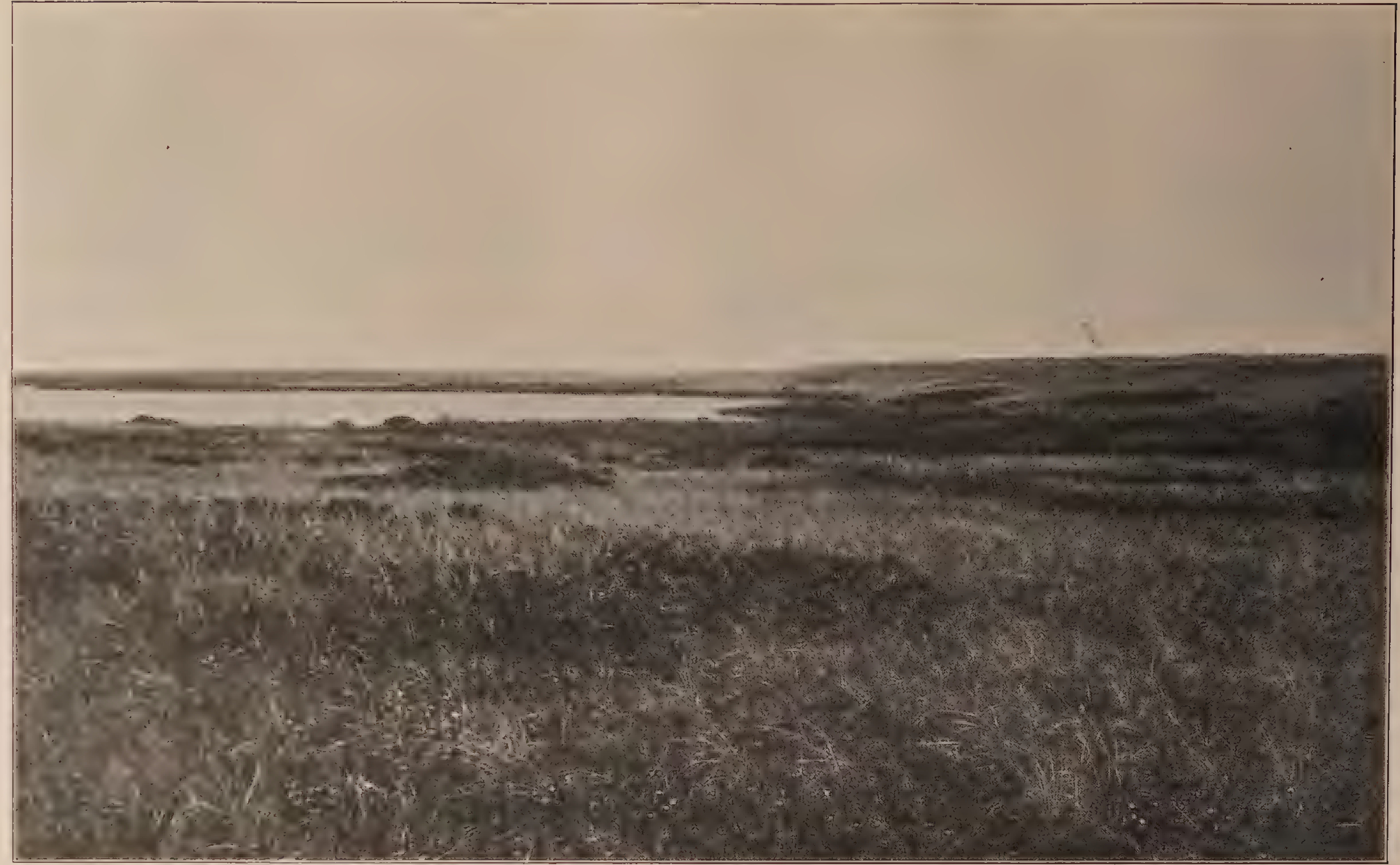
From Long Pond to Maddequet Harbor, the fosse consists of the

PLATE XV.



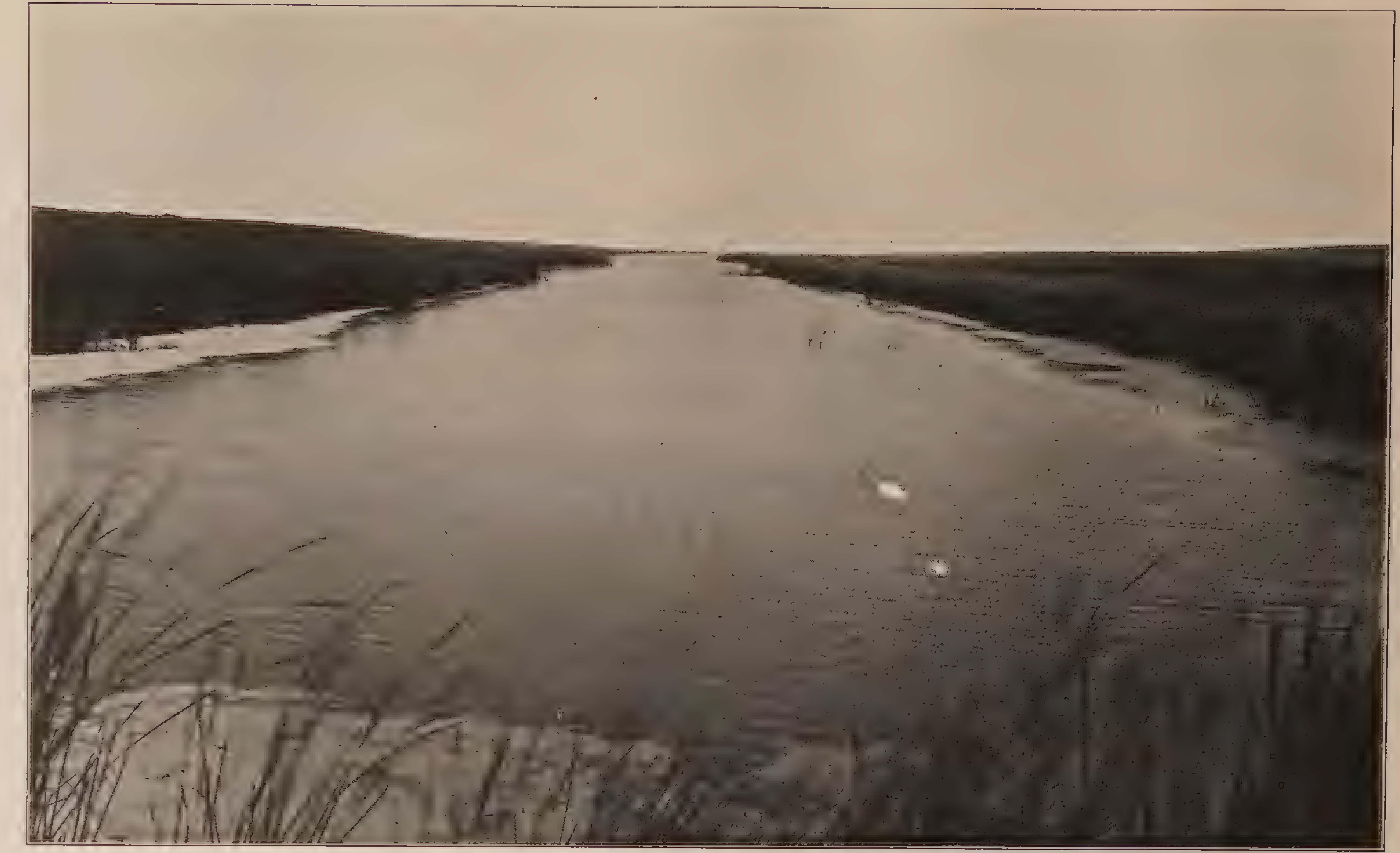
Hummock Pond from the "Bridge," looking Northeast.

PLATE XVI.



Contact Slope near Massasoit Bridge, Long Pond, looking Northeast.

PLATE XVII.



Long Pond from Massasoit Bridge, looking Southwest.

low, swampy land traversed by Maddequet ditch between Maddequet on the north, and Great Neck on the south. The valley of Long Pond north of Massasoit Bridge originated as a subglacial channel across the floor of the fosse in a similar manner to the valley of Hummock Pond.

THE APRON-PLAIN

The apron-plain on the eastern half of the island from Tom Never's Head to nearly the meridian of the town appears to be characteristically and beautifully developed, and does not present any peculiar features. It is an almost level plain, with a gentle grade from the top of the contact slope to the south shore, where it terminates in bluffs of moderate height. It is traversed by typical creases, which head at or near the top of the contact slope.

Two of these shallow valleys, Madequecham and Barnard's, as already mentioned, are deeper than the others, and do not originate at the head of the plain, but cut deeply through it, and can be traced more or less across the fosse to the foot of the kame hills. They are thus in the nature of subglacial channels, discharging their waters at the ice-margin, and keeping themselves open and free from the overwash while the apron-plain was forming. Some of the creases naturally run together during their course across the plain, and form one valley. Most of the larger ones in their lower courses are occupied by shallow, elongate ponds, separated from the sea by a strip of beach and dune sands. When for any reason the shore is cut back by the sea, the beach is maintained with practically the same width, so that the pond is encroached upon at its deeper end. Several of these ponds have thus almost if not entirely disappeared, although other causes may have aided in bringing this about in some cases.

I have never found any boulders on any of the apron-plains with the single exception of the neighborhood of Miacomet Valley, which case will be considered in that connection. Boulders up to fifteen feet in length are abundant on the kame hills, and in places strew the fosse to the contact slope, where they are only occasionally found.

It is difficult to draw any conclusions from the absence of boulders in any place where they should be expected to be found in the vicinity of the town, as so many have been removed for building purposes, as has been remarked by Professor Shaler ('89, p. 18). While the presence of boulders at any point throws a certain amount of light on the glacial problems in this region, their absence cannot always be regarded as of special significance for the above reason.

The apron-plain from Miacomet Valley to the western end of the island requires little further comment. That portion east of Hummock Pond shows on its northern half the presence of the old clay very close to the surface. This clay in many places appears on the surface, bare and unmasked by any drift material, and is diversified by rounded swells and swampy hollows, which topography is partly pre-Wisconsin, and partly the result of the overladen currents from the ice-front.

Between the arms of Hummock Pond, the plain appears as the isolated little apron-plain south of George Easton's Swamp known as Nanahuma's Neck. For the remaining distance, the plain shows the usual features of a gently sloping sandy plain traversed by creases, the creeks towards Smith Point being remnants of these shallow valleys. At one point west of Long Pond a crease which enters the pond as White Goose Cove passes completely through the head of the plain into the fosse, being an outlet for subglacial waters as other valleys already mentioned.

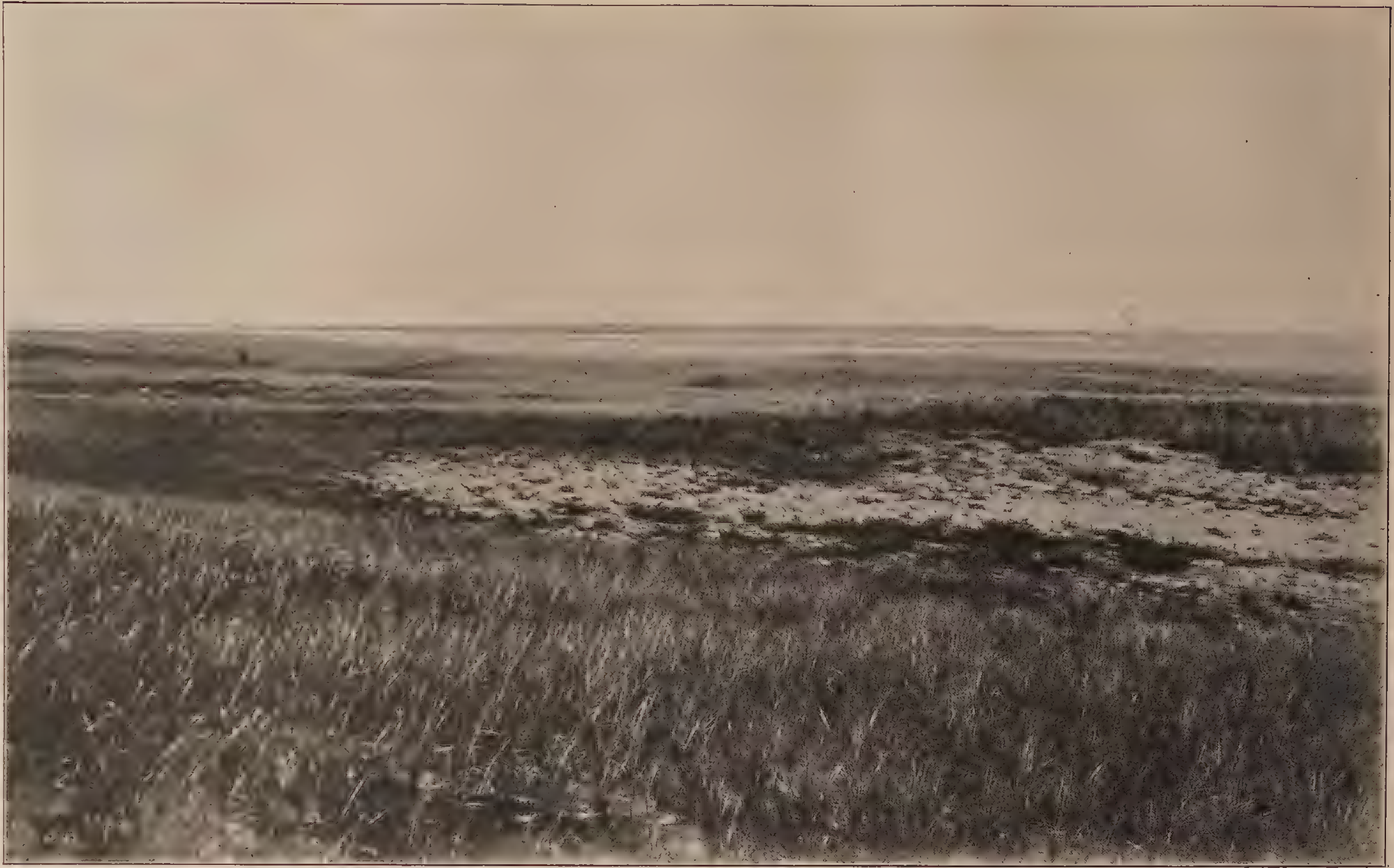
A view of diagrammatic character of the apron-plain on Tuckernuck Island as seen from Smith's Point is shown in Plate XVIII.

MIACOMET VALLEY

The section across the island of a mile or more in width which is represented in its northern part by the break in the kame hills, occupied by the harbor just east of the town, and by the disappearance of the fosse and ice-contact slope, can best be referred to as the Miacomet Valley region, as this valley with its lateral branches is the most peculiar feature of the region. This valley, like others on the apron-plain, has a northeasterly and southwesterly trend, and can be traced from the south shore, where its trough is filled by the waters of Miacomet Pond, to the harbor, which it enters just west of the almshouse. A western branch, which originates a short distance in front of the Mill Hill ridge about half a mile west of the mill, enters the main valley at the northern end of the pond. A crease coming from the northwest joins this valley at about the point of its debouchment into the main valley, while another coming from the same direction enters the main valley a short distance farther south. These two lateral valleys, while having a general northwest and southeast direction, which is what was to be expected from the direction of the corresponding portion of the contact slope, towards which they head, have for a short distance before entering the main valley an almost east and west direction.

The southern slopes of these valleys are considerably steeper than the northern ones, while a number of fair-sized boulders were found on the plain at the top of the south slope of the southernmost of these valleys,

PLATE XVIII.



Profile of the Apron-plain of Tuckernuck Island as seen from Smith Point.

and another group of about twelve boulders was noticed in a similar position with regard to a lateral valley farther north (Plate XXI). The southeast side of the main valley above the pond is considerably steeper than the other side, and at least one boulder was found on the plain above. This slope, from a point opposite the southernmost of the lateral valleys, for some distance north of the pond has much the same appearance as the eastern bank of Hummock Pond, which is known to be an ice-contact slope. Between the two main branches of Miacomet Valley is a tongue of land constituting part of the apron-plain, and with a gradient which brings it to the level of the valley floor at the confluence of the two branches. The presence of the boulders in the position mentioned so far to the south is another peculiar feature, I having never found them elsewhere on the island south of the contact slope, and their occurrence here with the absence of the marginal accumulations to the north make this region one of considerable interest.

It seems as if the phenomena presented may have been brought about in the following way. I am of the opinion that during the first part of the period during which the glacier was building the Nantucket moraine, a lobe of ice pushed south to the northern end of Miacomet Pond, resting against the southeast side of the valley, and the south side of the southernmost of the western lateral valleys. The overwash then built up an apron-plain to the south, while the ice before its retreat deposited the boulders in the first position noticed. The ice then retreated a short distance, forming the second contact, now the south side of the second lateral valley, keeping its position against the southeast side of the main valley, but somewhat farther north.

A second retreat then took place in a similar manner, forming the south slope of the third valley, and leaving the group of boulders in the position mentioned. After each retreat, the overwash built up the northern side of these lateral valleys, but with a much more gentle slope, while it was prevented from entirely filling the valleys thus formed by the strong streams from the ice-front which, finding these natural channels, kept them open.

Later, when the lobe had nearly disappeared, the wash-plain between the two main branches of Miacomet Valley was formed. All this took considerable time, so that soon after the lobe had shrunk back to the main ice-mass, the latter may have commenced its final retreat to the north. In this case, the glacier would have maintained that portion of its front in the position just south of the harbor for a short time only, which fact, combined with the instability of position at this point, would have resulted in the absence of the definite marginal features mentioned.

That a lobe occupied the position described is further shown by the presence of a small crease entering Hummock Pond from the northeast, a short distance below the "Bridge." A crease coming from this direction at this point could only result from the presence of a lobe in the position supposed. The clayey lands mentioned just south of the Mill Hill ridge also have somewhat the appearance of a fosse, the head of the apron-plain proper a short distance to the south appearing as a low contact-like slope. This is noticed as far west as Hummock Pond, where it joins the well-defined contact slope of the main ice-front.

The Mill Hill ridge, resembling as it does the kame hills and containing numerous kettles, may have been formed as a kame deposit at the time of the extension of this lobe, the disappearance of the lobe and the resting of the main ice-front for a time in this position developing the contact slope noticed on the north side of this morainal ridge.

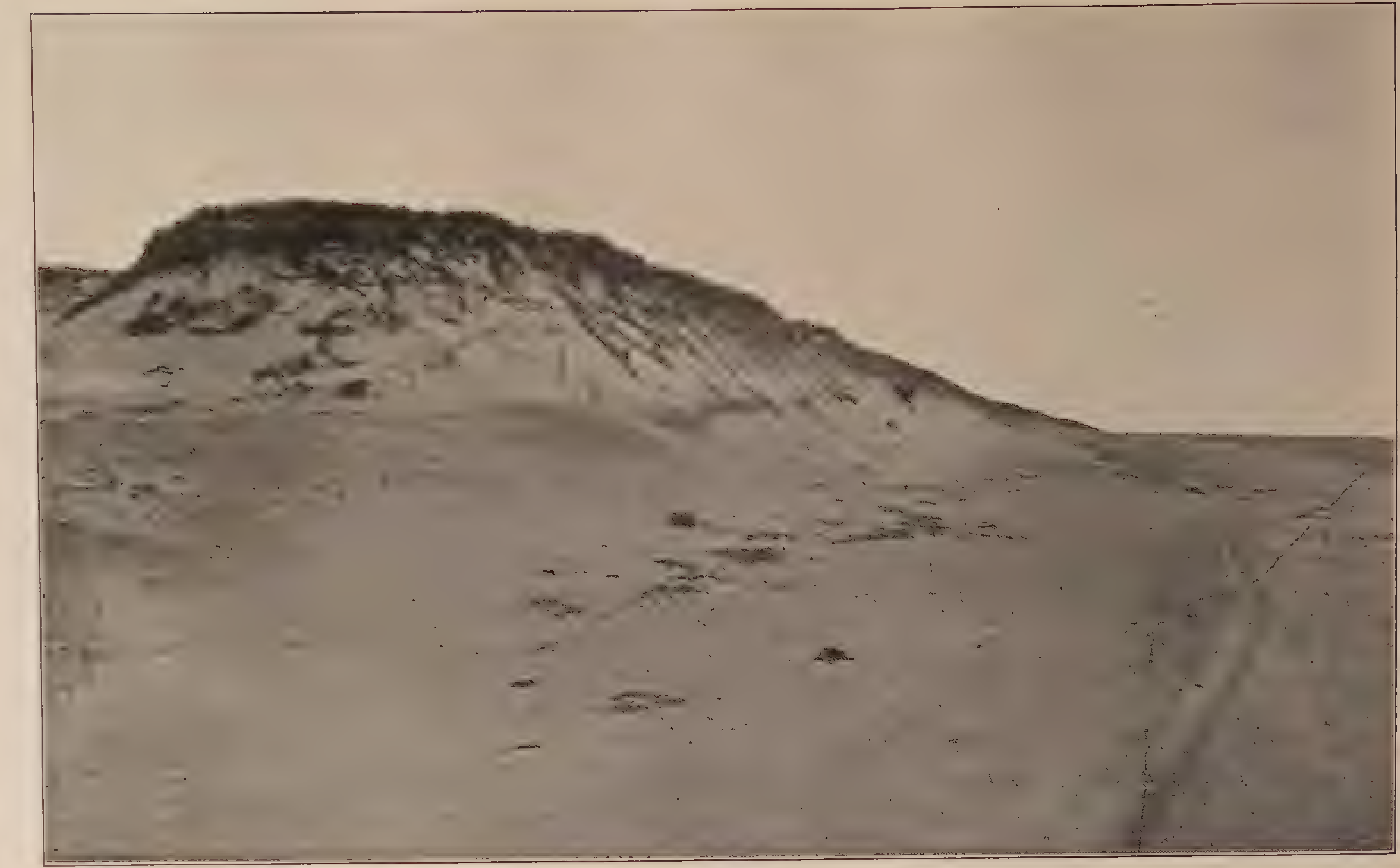
The lateral valleys which enter Miacomet Valley from the west head near the contact line of Hummock Pond, and are normal creases, at least in their upper portions. The peculiarities of slope noticed in their lower portions, with the sand and gravel deposits between them, including the tongue of land between the two main branches of the valley, might be the result of converging streams on a developing apron-plain; but this could not account for the presence of the boulders in the positions in which they were found, or the absence of normal marginal features farther north. The boulders could only have reached their present position through the agency of ice, either glacial or dropped from bergs from the ice-front if the region were submerged. As will be shown farther on, all the evidence goes to show that the glacial features of Nantucket were formed above sea-level, and that there has been no great change in elevation since that time. The supposition that a lobe of ice pushed down this shallow depression, somewhat in the manner described, seems then best to explain the peculiarities noticed in this region.

TRANSPORTED MATERIAL

No special study was made of the material making up the moraine, but it has been examined and described at some length by Professor Shaler ('89, pp. 26–28). Some pebbles of quartz-porphyry were found, however, which cannot be distinguished from that occurring at Mt. Kineo, Maine. Some Indian arrowheads of the same material, and chips showing them to have been made here, and not brought from the mainland, were also found.

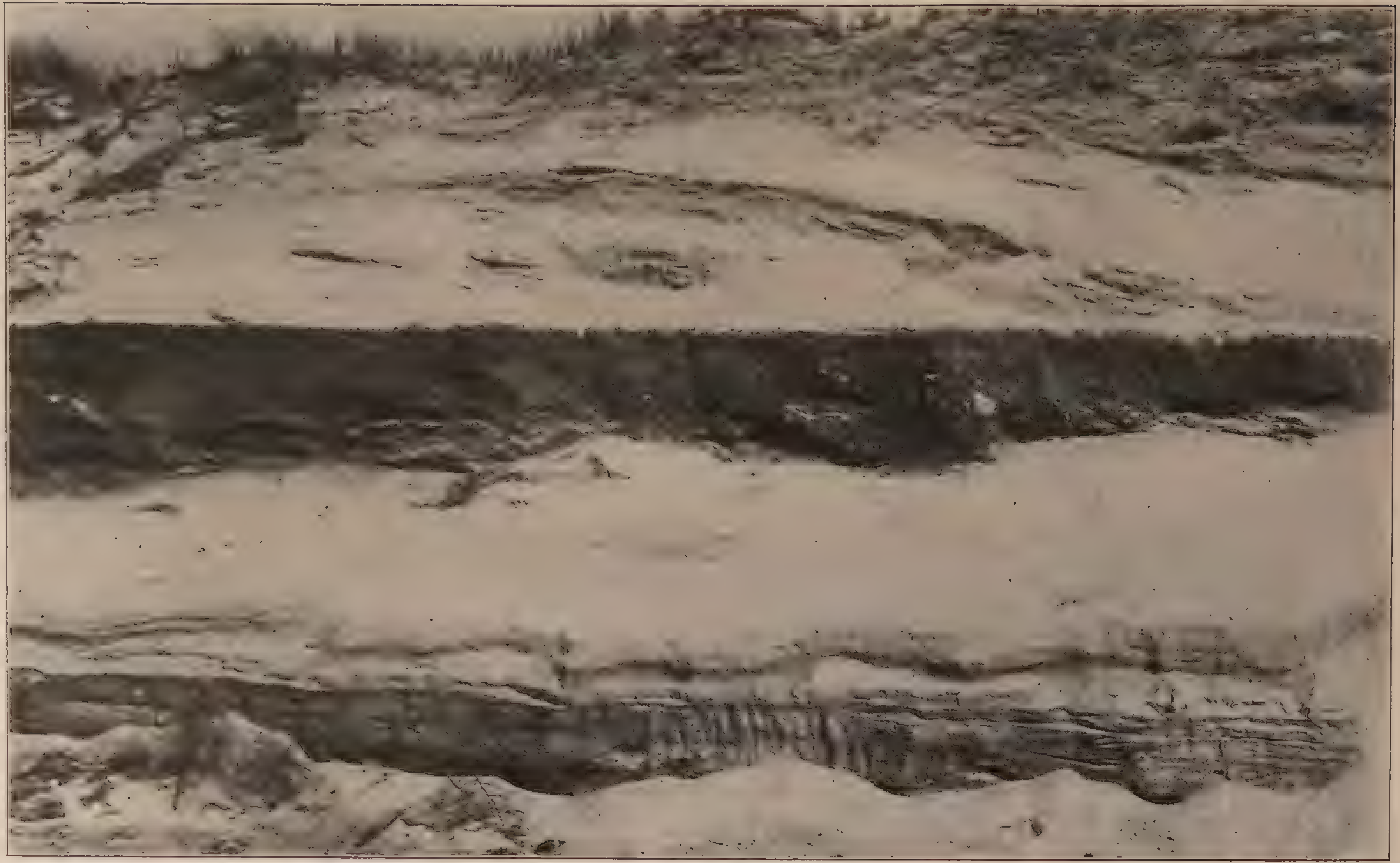
If this material came from Mt. Kineo, it would indicate an almost due south direction of motion for this portion of the ice-sheet. Por-

PLATE XIX.



Bluff at South Shore.

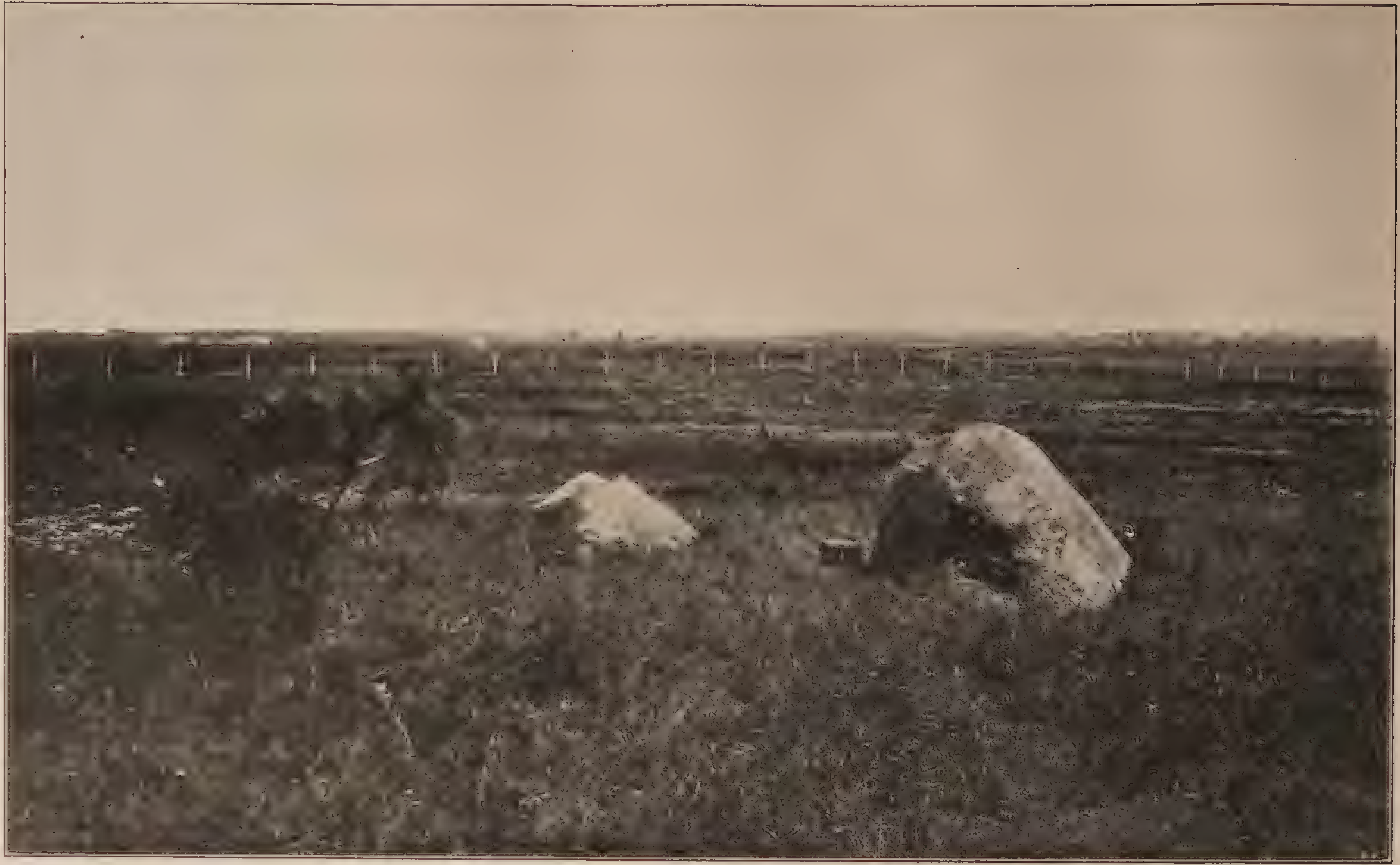
PLATE XX.



Detail of Bluff at South Shore.

Showing overwash material of apron-plain, overlain by dune sands.

PLATE XXI.



Boulders on Apron-plain, Miacomet Valley, looking North.

phyry which cannot be distinguished from the Mt. Kineo material occurs nearer by, in the vicinity of Boston, and perhaps elsewhere.

Professor Shaler mentions (Shaler, '89, p. 26) "somewhat angular fragments of volcanic breccias of a type unknown to me in any part of southern New England, though they much resemble the ash beds and breccias of the eastern portion of the shore of Maine, especially those found near Eastport."

Of the pre-Wisconsin glaciation in this region very little is known; but any drift material deposited here would have been shoved in front of the Wisconsin ice-sheet, and accumulated as part of the moraine of this later ice advance. In case of different points of origin for the ice-sheets which have reached this district, we may expect to find a mingling of materials from widely separate regions.

As will be shown in the latter part of this paper, there is every reason to believe that the last ice advance came from a direction considerably east of north.

POSTGLACIAL DEPOSITS

The postglacial deposits consist entirely of accumulations of peat in the swamps and kettle ponds, and various beaches and sand-spits. These have been fully discussed by Professor Shaler and others (Shaler, '89), and Dr. Gulliver has made a special study of the beaches and sand-spits (Gulliver, '04).

A few words may be said in regard to the Coatue sand-spit, with its curious points or cusps on the harbor side, and which, with the configuration of the bottom of the adjacent bay, Professor Shaler has called one of the most puzzling on the Atlantic coast (Shaler, '89, p. 12). It is made up from the waste from Coskata (Plate XXII), and even that from the eastern shore of the island which has worked around Great Point (Plates XXIII and XXIV), and has of course gradually grown out from Coskata in the manner common to such formations. The outer side presents the long regular line characteristic of wave action on such material.

The best explanation of the cusps seems to be that of currents sweeping in regular curves, and scouring out the arcs between the cusps as the spit became extended. The spit is built upon the old clay, and it would seem as if the irregular surface of the latter might in some measure be responsible for the curious shape taken by the overlying deposits, the sands spreading out more in the shoaler waters where the clay rose nearer to the surface, and thus forming the broader cuspate portions, while in the deeper places, the same amount of material would be used up as a fill and base for a comparatively narrow portion above sea-level.

Just off First and Second Points are two of the deepest places in the harbor, but the points themselves may be built up in shallow water, and their further extension harborward limited by the rapidly increasing depth of water. The cusps, however, seem to have grown from the main portion as if they lay in nodes or eddies between the currents. This has been shown by Professor Shaler in the presence of successive beaches with small lagoons between, which are noticeable on most of the points.

The curious regularity and repetition of the cusps and arcs would seem to indicate a great uniformity in the currents scouring the upper harbor, and they are no doubt much influenced by the topography of the sea bottom. If these points are due to the undulating surface of the sea bottom, they would seem to indicate a series of folds and troughs in the underlying clay, the axes of which would have a northwest and southeast direction. This direction agrees exactly with that of the trough in which the Sankaty beds were laid down, and being at right angles to the general direction of movement of the ice of the Nantucket lobe, naturally suggests any such folding was due to the pressure of the ice-thrust as has been noticed on Long Island. But the evidence given by the Sankaty beds would point to such folding having taken place previous to the deposition of those beds.

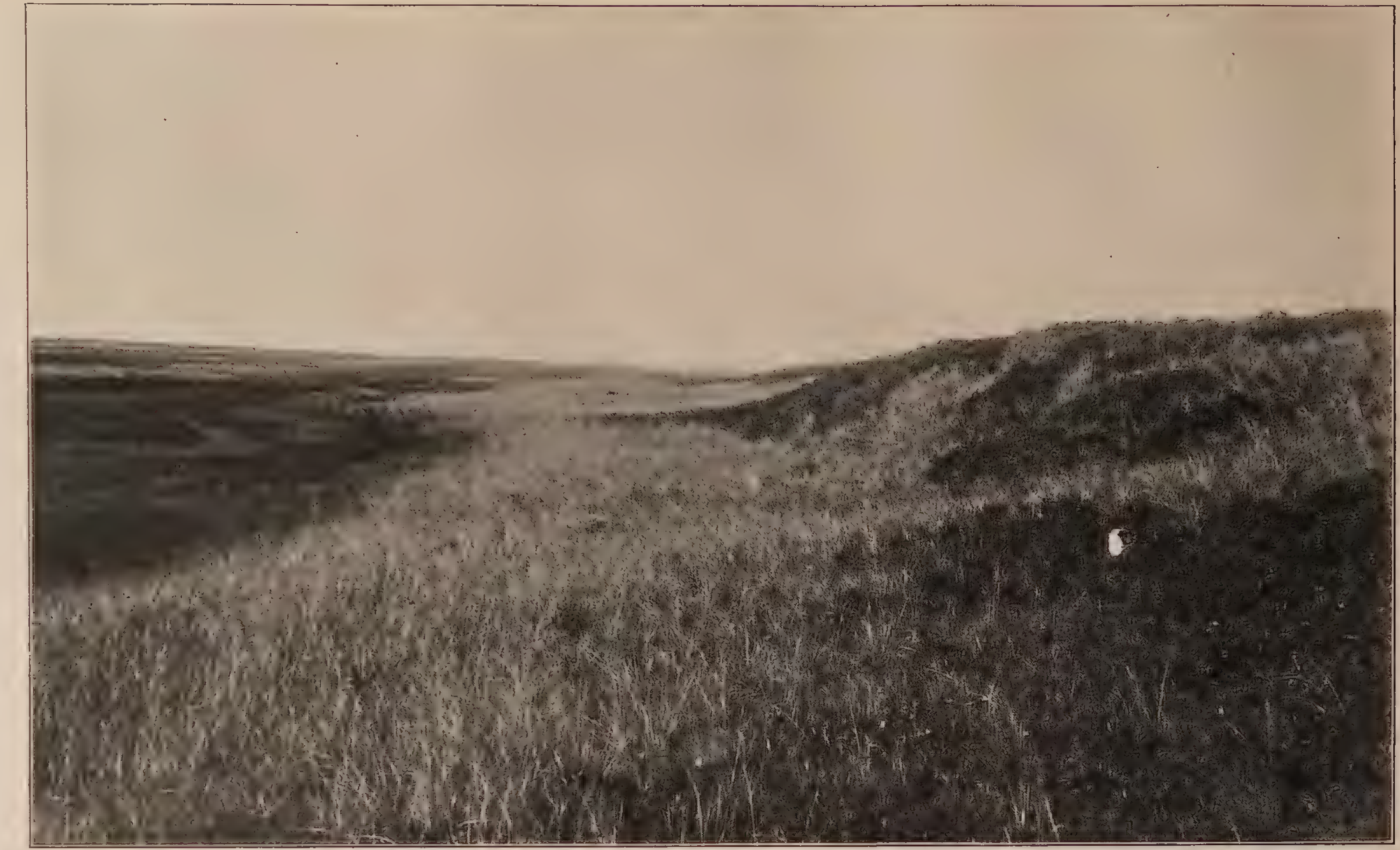
This would then relegate the time of folding to early or even pre-Wisconsin times.

CHANGES IN ELEVATION OF NANTUCKET

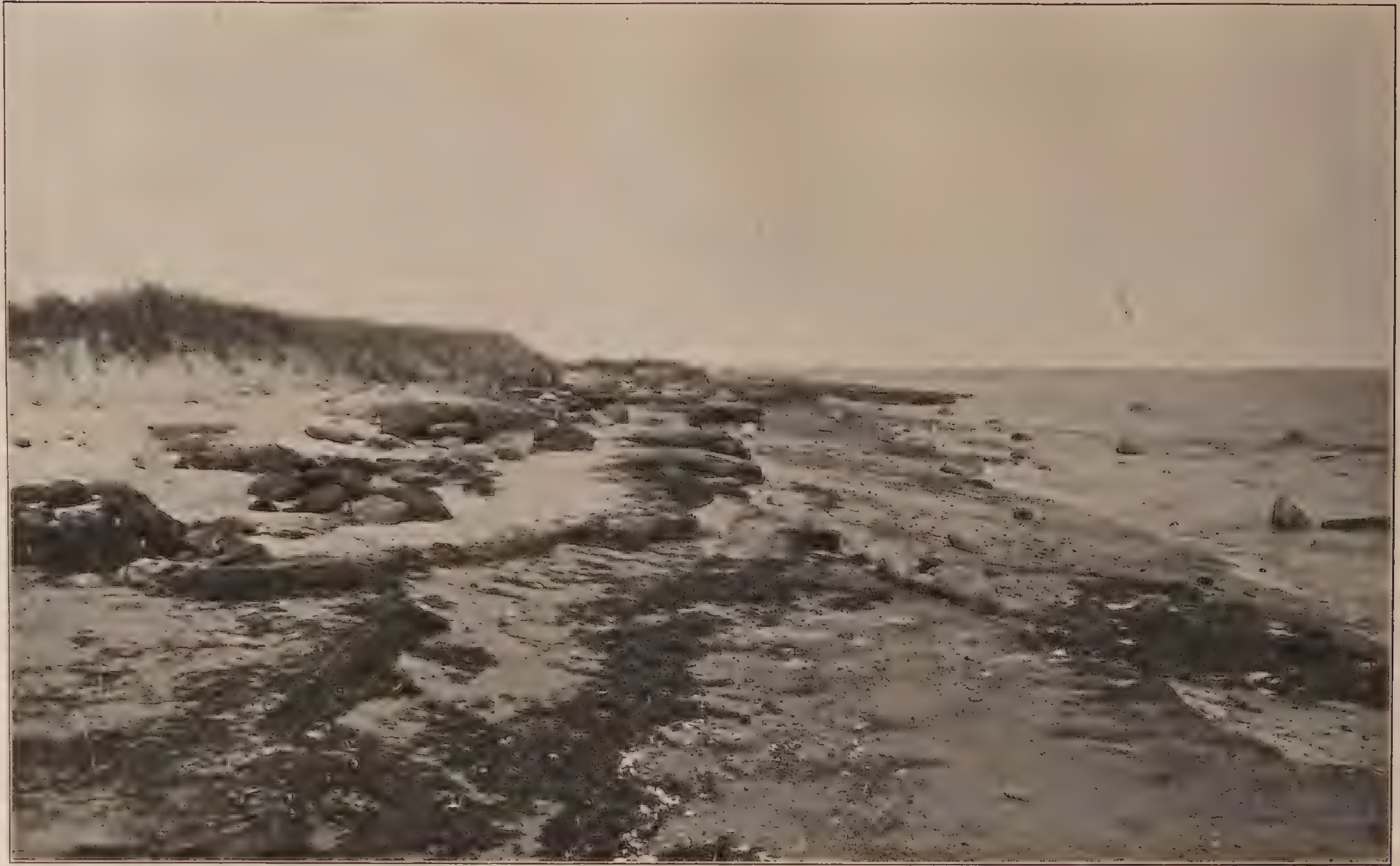
There has been some discussion in regard to the elevation of this region relative to the present sea-level, during and subsequent to the period occupied by the accumulation of the deposits of this last glacial period.

The evidence given by the deposits at Sankaty Head indicates a considerable less elevation for this area for a certain length of time preceding the advance of the ice to this point. A reëlevation must have then taken place, for observations made all over the island show conclusively that, during the greater part of the time at least in which the present moraine was formed and subsequently, the elevation of Nantucket has not varied greatly from what it is to-day. The kame hills show the characteristic steep sides and rounded knobs, while the kettles are often deep and show less filling in than might even be expected to result from the rains and snows in the long period of time since the Wisconsin ice-sheet began its retreat from this region. For these accumulations to have taken place below sea-level would have necessitated their being subjected to the severe wave action of the open Atlantic as they rose to their present position, and it seems impossible

PLATE XXII.



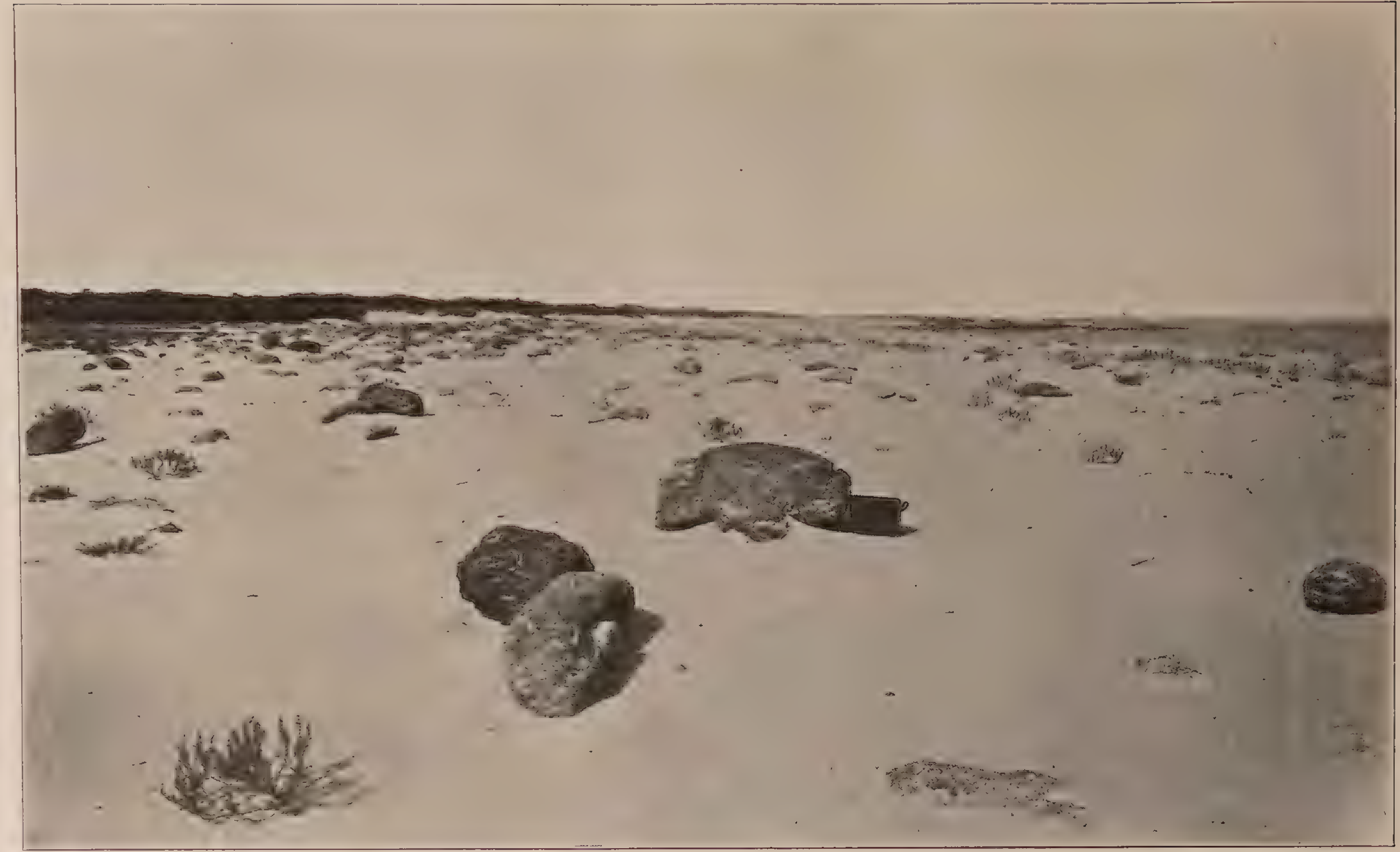
Old Beach and Bluff, West Side of Coskata Island, looking North.



East Side of Coskata Island, looking North.

The exposure of this old peat bog, once inland, shows that wave attack has cut back the shore line.

PLATE XXIV.



Coskata Spit, Strewn by Waves with Peat Blocks.

that these kame hills and other marginal deposits, composed as they are of loose and uncemented sands and gravels, could have maintained their present characteristic features if exposed but for a few hours to the surges of the open ocean.

There are no shelves or raised beaches observable on any part of the island, while large boulders, which are plentiful on the kame hills and occasional as far south as the ice-contact slope, are not found on the apron-plain, with the single exception of those already mentioned in Miacomet Valley. If this region were submerged when the ice-front stood here, we should expect to find numerous boulders on the apron-plain where they would have been dropped by floating ice. There are also no sand-plains or deltas to be found on Nantucket as might be expected to be the case if streams from the ice-front were discharging into a body of water, while the shallow valleys on the apron-plain have every appearance of having been formed by streams from the ice-front on a plain developing above sea-level.

There is some slight and unsatisfactory evidence which seems to point to an upward movement of a few feet in very recent times. This is found in the bluffs of erosion at different points along the inner side of the harbor, and to which the sea does not now attain. They are especially noticeable just east of the town (Plates XXV and XXVI), and about Polpis Harbor, occurring also at one or two intermediate localities. This evidence is very doubtful, as the erosion may have taken place before Coatue spit was built, when these shores were directly exposed to the attacks of the larger waves of Nantucket Sound. There is also another factor which adds to the uncertainty of the evidence. These bluffs may possibly be artificial, due to the removal of material for the filling in and reclaiming of marshy tracts between the higher lands and the present beach. I have been informed that this is known to have been done in several cases.

The old bluff and shore line on the west side of Coskata Island were formed by the sea waves before the deposition of the great mass of the Coatue sands. The sea is now fended from these bluffs by nearly a mile of these later deposits, but the old beach is beautifully shown by the presence of a heavy growth of beach grass which does not grow on the better soil adjacent (Plate XXII).

A similar old erosion bluff is found at the western limit of the kame hills in Maddequet, the high land here being attacked by the sea waves before the building of the Eel Point spit. Even on the north side, these old bluffs are separated from the sea by 150 feet of beach and dune sands.

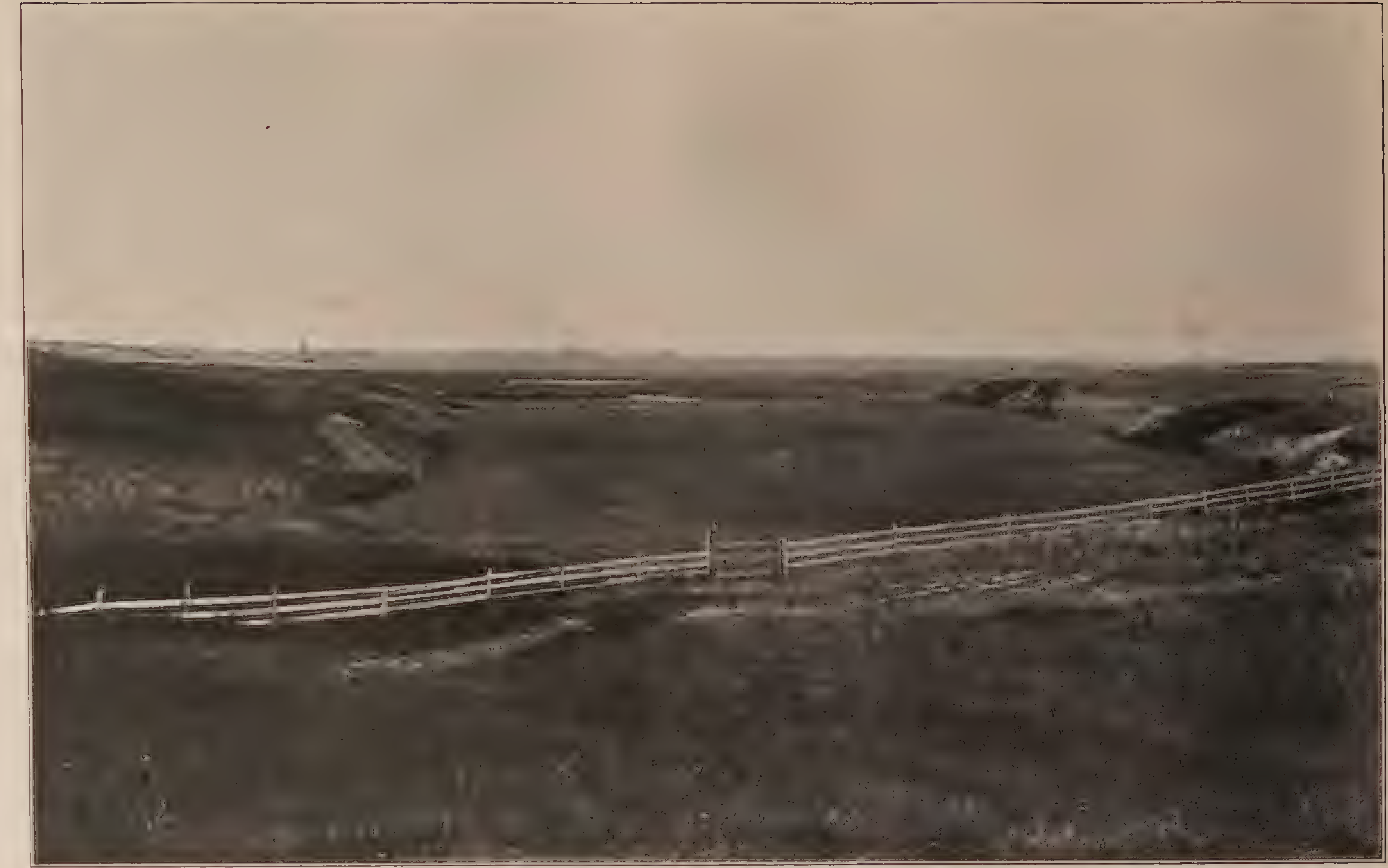
Cupaum Pond, occupying a depression in the northern end of the trough of Hummock Valley, was formerly, as records show, an open inlet accessible to small boats, but it is now entirely shut off from the sea by a strip of beach, as is the case with the other ponds lying near the shores of the island.

These sand deposits, however, are simply the accumulations in eddies or at present protected places of material derived from points where erosion by the sea waves is most active.

PLATE XXV.

Bluffs East of Nantucket Harbor.

PLATE XXVI.



BLUFFS EAST OF NANTUCKET HARBOR.

CHAPTER VI

MARTHA'S VINEYARD AND BLOCK ISLAND

MARTHA'S VINEYARD

I HAVE not visited this region, but it has already been so thoroughly studied, especially by Shaler and Woodworth (Shaler, '85–86, and Woodworth, '97, 2), that a mere summary of the facts seems all that is necessary here.

On Martha's Vineyard, as on Nantucket, the glacial deposits are laid down on an earlier eroded land surface, but here much older rocks occur than are found anywhere on Nantucket. The oldest beds exposed on Martha's Vineyard are the lignitic and leaf-bearing clays which have been referred to the lower Cretacic, and by Marsh even to the Jurassic, on the ground that they are the strategraphic equivalents of the Potomac formation in Maryland. These are followed by the marine Upper Cretacic, and these in turn by Tertiary and Pleistocene deposits. The older beds are exposed in but a few places, but probably underlie the drift in the western highlands, and are notably revealed in section in the Gay Head Cliffs (Woodworth, '97, 2, p. 198, and Fig. 1, p. 207). The beds have been much folded, and numerous unconformities occur, as has been shown by Shaler and Woodworth.

Cretacic pebbles occur in the drift, and have been found near Indian Hill, and on the eastern shore of Lagoon Pond. Pebbles containing Eocene fossils have also been found in the drift of Chappaquiddick Island (Brown, '05). These drift pebbles have probably been transported but a short distance from beds now concealed under the drift and morainal accumulations to the north.

Beds which Woodworth has correlated with the Sankaty deposit occur on Martha's Vineyard above a bed containing what are apparently glacially transported boulders. A great folding of the beds now took place which Woodworth has called the Gay Head diastrophe (Woodworth, '97, 2, p. 207), and which seems to be due to the thrust of the Wisconsin ice-sheet. Later deposits, but still antedating the last ice advance, occur in the horizontally disposed clays and sands of the Tisbury series.

The deposits at Sankaty Head on Nantucket do not appear to have been folded, and the dip which they exhibit seems rather an initial one than one due to subsequent movement. They appear also, as has been shown, to have been laid down in a trough in an old land surface of pre-Wisconsin till which may be the equivalent of the "lower boulder bed" on Martha's Vineyard. This trough may be due to folding from the ice-thrust or may have resulted from erosion in an interglacial period. The fact that the Sankaty Head deposits on Nantucket have not been subjected to the folding noticed in the group on Martha's Vineyard would seem to place the deposition of these latter at a somewhat earlier period, although the thrust of the Long Island lobe and its ability to produce folding may have been much greater than that of the Nantucket glacier near its front on Nantucket.

The evidence in this region of an earlier ice-sheet than the late Wisconsin seems to rest on the presence of transported material of large size in the "lower boulder bed," mentioned above, with perhaps some support from one or more of the earlier periods of folding.

The great glacial accumulations, as on Nantucket, are all from the last ice advance; those on the eastern half of Martha's Vineyard, as already shown, were formed by the Nantucket lobe, the great morainal deposits capping the highlands to the west being due to the Long Island lobe (Plate II *a.*).

The two lobes met at the northern part of the island, forming from there to and beyond Manomet Hill an interlobate moraine.

The moraine on the eastern portion of the island, being formed on low land, does not rise much above the apron-plain to the south, resembling in this respect the conditions found on Nantucket. The western moraine, however, is built upon the high land of the older rocks, forming a hilly ridge with steep descent to the overwash plain to the southeast. It is thus on a large scale what the Mill Hill portion of the Nantucket moraine was shown to be on that island, and similar in this respect to the moraine in the Cape Cod district, which will be described later.

The whole southern and southeastern portion of Martha's Vineyard consists of a plain, gradually descending towards the south. This is the apron-plain, and, as in the case on Nantucket, is made up of finer water-worn material, and is traversed by shallow valleys, the creases carrying the waters from the ice-front as the plain developed from the overwash material (Shaler, '85–86, and Woodworth, '97, 1).

Postglacial erosion and deposition have taken place here as on Nantucket. The erosion is mainly that due to the action of the sea in exposed places, glacial deposits generally in most localities exhibiting but slight traces of denudation in postglacial times.

The deposits also are inconspicuous, being mainly small accumulations, such as peat and bog-iron ore, and the formation of barrier beaches and sand-spits from the waste along the cliffs, or from material brought from the sea floor by the action of waves and currents in shallow water. These sand deposits are found principally along the south and southwest shores, and the eastern side of Chappaquiddick Island.

BLOCK ISLAND

This small island, only eleven square miles in area, furnishes a link between the islands to the east and Long Island on the west. It is, as we have seen, a part of the terminal moraine of the Long Island lobe in its first stage or period of maximum advance, and presents similar evidence. In its underlying structure it also exhibits great similarity to those regions, and as Dr. Hollick has said (Hollick, '96, p. 17), "has thus been brought into line geologically with Long Island, Martha's Vineyard, and Nantucket."

The oldest strata here are the Cretacic clays, which are overlaid perhaps by a small amount of sandy clays of Tertiary age. These were squeezed up and folded by the thrust of the Long Island lobe, the dip being noticeably toward the northwest, or against the direction of thrust in this region. The whole was then somewhat eroded by the ice, and buried under a thick morainal deposit of the same age as that forming the surface features of Nantucket and Martha's Vineyard, and of the outer moraine of Long Island. Here, as in those regions, the surface features are distinctly glacial, exhibiting the knob and basin topography peculiar to morainal deposits, the highest point being reached in Beacon Hill, 211 feet above sea-level.

It is doubtful if the strata underlying the glacial deposits presented a land surface exposed to erosion in pre-Wisconsin times, as was probably the case in Nantucket and Martha's Vineyard, but the effect of the ice-thrust was to throw these older beds up into a ridge along the line of the ice-front, thus forming a support for the glacial deposits, upon which they were laid down.

Erosion is now going on more or less rapidly by the ocean waves, except on the northern side, where it is less exposed, and unless interrupted by new conditions, will result, geologically speaking, in the disappearance of this island in the near future, as will also be the case with neighboring areas of similar character.

CHAPTER VII

RETREATAL PHENOMENA OF THE LATE WISCONSIN ICE-SHEET

UPPER CAPE COD

AT the close of the Nantucket stage, the Nantucket lobe began to melt back, its front perhaps making slight halts, and forming insignificant moraines. At any rate, a certain amount of coarse material was left by the retreating ice, to be buried under the overwash when the front paused for the longer period, constituting the Cape Cod stage along the line indicated by the Cape Cod moraine. When this coarse material was deposited on high land, it was not always buried, the apron-plain forming around it. Such a case seems to be revealed in the morainal-like material at Falmouth Heights. Some of the deposits in Nantucket and Vineyard Sounds are no doubt of a similar nature, as boulders have been reported by fishermen as present on some of the shoals. Shaler, in his report on the geology of Martha's Vineyard, represents the shoal known as the Middle Ground between the Vineyard and the Elizabeth Islands as of a morainal nature (p. 305, Fig. 55).

As on Nantucket, so in the Cape Cod region, the oldest exposed formation is a clay, probably an old till of the same nature and age as that seen to underlie the late Wisconsin drift of that island. It underlies the interlobate moraine, and reaches the 200-foot contour in the region to the northeast of Pine Hill, where its surface is swept nearly clean by the ice of the Nantucket lobe. In strong contrast with this surface is the morainal belt which is built upon it on the west, the boundary between the two being the prominent and finely developed contact slope, previously mentioned. While boulders or any sort of drift materials are extremely scarce on the clay surface here, boulders of large size abound throughout the morainal belt, even to the foot of the contact slope, adding to the distinctness of the line of demarcation.

This clay seems to have been folded and apparently also underlies the east and west morainal ridge from Monument River to the eastern shore of the Cape beyond Orleans.

Above this clay are the horizontally stratified and generally undisturbed clays, which I am of the opinion were formed in connection with the last ice advance, in a manner that will be shown later. It is doubtful if the clays to the south of the moraine are to be exactly identified with those to the north in their time and mode of origin, but definite knowledge of any of these underlying clays is as yet very meagre.

Above these deposits are those of undoubted glacial origin, the stratified sands and gravels of glacially transported material, the areas of till, and the surface drift, with its numerous large boulders along the line of the moraine.

When the ice-front paused in the Cape Cod position, the whole area south of the moraine received the overwash, and became built up into an apron-plain. Numerous large masses of ice were left in this region in the retreat from the Nantucket position, and the apron-plain building about them, their eventual melting out left the depressions now occupied in many cases by the numerous ponds and lakes. The fact that these ponds, surrounded by porous sands, are found at different elevations is no doubt due to the presence at varying heights of the underlying clay, furnishing an impervious layer and water-level at different elevations.

These depressions in the apron-plain are not in most cases true kettles, but ice-block holes, formed by the melting out of ice-masses, about which the apron-plain was built. Some of them, as Great Pond south of Barnstable, are of large size, this depression being thought by Woodworth ('97, 1, Fig. 4) to have even been occupied while the apron-plain was forming by a lobe of ice, which pushed south of the moraine to the east of Shoot Flying Hill. True kettles are found more in the morainal belt, or immediately to the north.

It will be noticed that here the ice-front lay along a ridge of high land, making the case analogous to that of the western highlands of Martha's Vineyard. In both cases, the apron-plain was not built up to a level at all approaching that of the morainal ridge, so that a steep gradient was offered to the streams carrying the overwash material, causing violent currents, and a less regular development of the apron-plain than is found on Nantucket, except in the Mill Hill locality, where the case is similar.

Along this morainal ridge, steep and apparently ice-contact slopes occur in places on the north side, and there is some evidence of the development of a fosse and kame hills. Immediately to the north of the moraine, throughout most of its length, there is a more or less irregular zone of low-lying land with swamps and kettles, which is followed farther north by rising ground, with rather a knob and basin topography, and strewn with numerous boulders. Some of these deposits may be in part sand-plain formations, and the boulders dropped by bergs in the next, or Lake Shaler stage, soon to be considered.

For further details of this portion of Cape Cod, special reference is here made to the following papers: Shaler, '96–97; Upham, '79, 1 and 2. The formations of Lower Cape Cod, however, from Eastham to High Head, have been made the subject of special investigation, and their discussion will form Chapter VIII of this paper, under the general title of "Lake Shaler: a Glacial Lake in the Cape Cod Region."

ELIZABETH ISLANDS

As the front of the Nantucket lobe retreated from Nantucket to its position on Cape Cod, the Long Island lobe melted back also, as we have seen, halting with its front along the line indicated by the moraine of the Elizabeth Islands, southern Rhode Island, Fisher's and Plum islands, and the northern part of Long Island, forming what has been termed the Fisher's Island-Elizabeth Islands stage of this lobe.

The Elizabeth Islands are owned by private parties or corporations, which naturally makes them difficult of access, but even as seen from the water, they exhibit their unmistakable morainal character. They were, through the courtesy of the owners, visited by Dr. Hollick, in August, 1898, and the results of his explorations he has set forth in a paper entitled "A Reconnoissance of the Elizabeth Islands" (Hollick, '01), to which the reader is referred. As was theoretically expected, Dr. Hollick found here, as in other regions we have considered, that the glacial deposits are supported by a ridge of Cretacic clays. This ridge, as in the ridges of older deposits on Martha's Vineyard and Cape Cod, coincides with the line of the moraine, and is evidently due to the squeezing up of the Cretacic rocks by the force of the ice-thrust. This condition is shown by Dr. Hollick in Fig. 2, Plate XIV, of his paper.

From the Elizabeth Islands, the ice-front ran westward, its moraine next appearing above sea-level in the "Charlestown moraine" of Woodworth ('96, p. 152), in southern Rhode Island. Fisher's, Plum, and Gull islands, with their morainal deposits and characteristic topography, indicate the position of the ice-front from here westward to Orient Point, from which locality it can be plainly traced in the northern moraine of Long Island to Staten Island, crossing the outer moraine, as Woodworth has shown, a short distance to the east of the city of Brooklyn.

FISHER'S ISLAND

This island has recently been studied by Myron L. Fuller, and his results embodied in a paper entitled the "Geology of Fisher's Island, New York" (Fuller, '05). Mr. Fuller found here the same general evidence that has been noted in other portions of the region under consideration, but here bed rock (a light gray granite) was reached in a drilled well, at the depth of 281 feet below sea-level. Above this granite is a layer of blue clay about 20 feet in thickness, which Mr. Fuller considers as of Cretacic age. This clay is apparently unfolded and very little disturbed. Above it, however, occurs a thick series of clays, sands, and gravels, the upper members of which are squeezed up and folded as on Block Island, and the whole capped by glacial drift and till of varying thickness (Fuller, '05, Fig. 4). The surface features, as on Block Island and the Elizabeth Islands, are distinctly morainal, exhibiting the characteristic knob and basin topography with the presence of numerous large boulders.

CHAPTER VIII

LAKE SHALER: A GLACIAL LAKE IN THE CAPE COD REGION

It has been shown that the Nantucket lobe in retreating from the Nantucket position made a stand at Cape Cod, forming the marginal features of what has been termed the Cape Cod stage. Lower Cape Cod, however, from Eastham Centre to High Head some distance back from the main morainal accumulations, presents some formations exhibiting peculiarities which separate them from those of the Cape Cod stage.

In 1896 Dr. A. W. Grabau made a hurried survey of this region, with the result that he concluded that the deposits found in the townships of Eastham, Wellfleet, and Truro were in the nature of sand-plains, delta formations built out from the front of the retreating glacier into a body of ponded water; and this view he presented in a paper under the title "The Sand-plains of Truro, Wellfleet, and Eastham," read before the Boston Society of Natural History, January 6, 1897 (Grabau, '97). As Dr. Grabau has pointed out, these sand-plains are very numerous, but can be referred to three series at different elevations. A fourth series might possibly be recognized in the small area at Highlands.

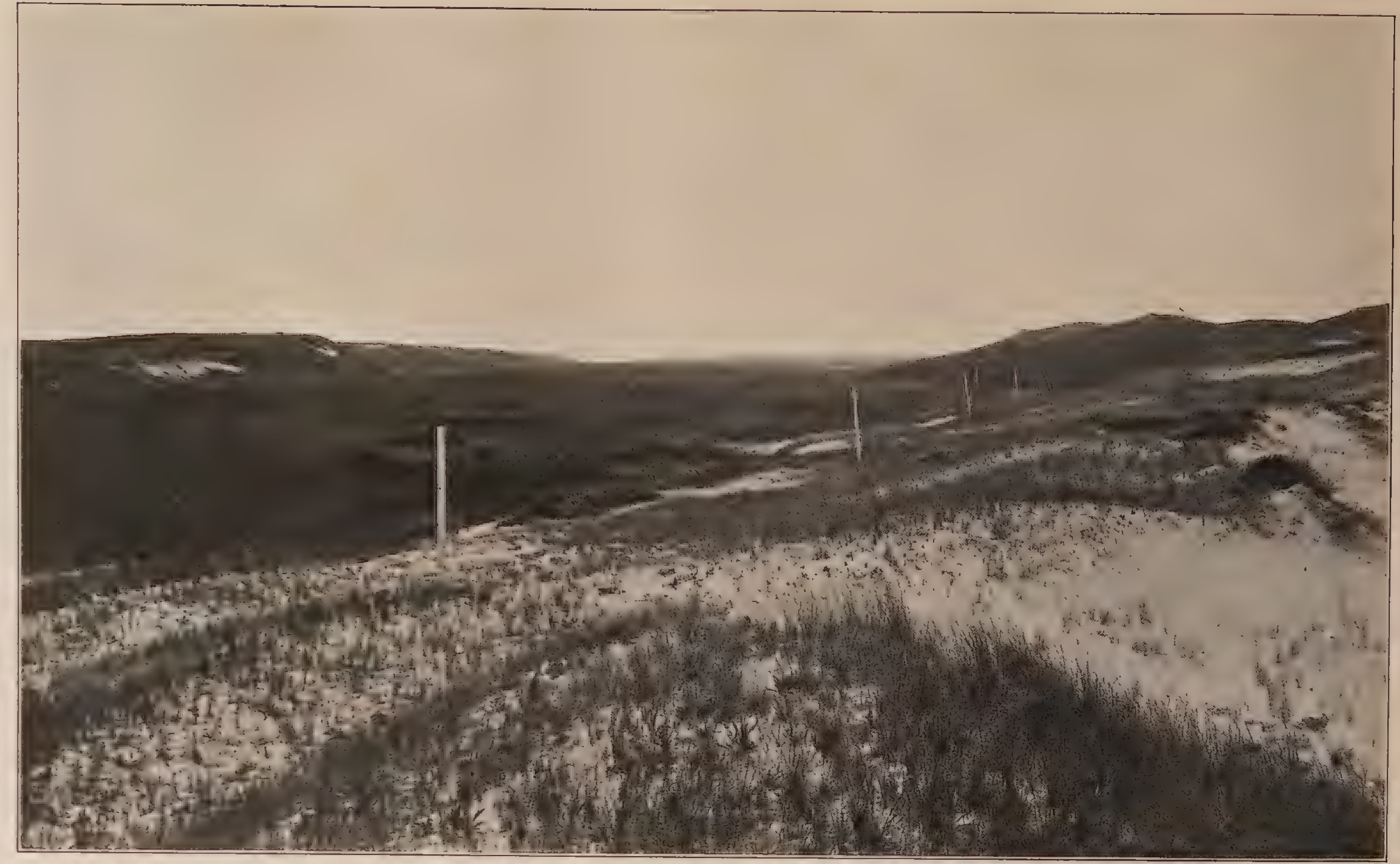
During the past summer (1905), I made as thorough a study as possible of the formations of this region, with an investigation of neighboring points on the Cape which seemed in any way connected with the problem or likely to shed any light upon it.

It may be said here that few sections are available for study in this region, and these yield little information, the solution of the problem depending almost entirely on the interpretation of topography and surface features.

It will be shown that these sand-plains were formed after the Cape Cod stage, and are our principal evidence of conditions in this region about to be described.

As the Cape Cod stage of the Nantucket lobe came to a close, and the ice began to melt back, what might be termed a third stage was inaugurated in this region. It will be shown that the ice first melted back along that portion of the moraine of which Sandwich is the centre, still holding its front in position eastward of Barnstable, and pressing against

PLATE XXVII.



Old Erosion Bluffs at the left, Dunes of Provincetown Sand Spit on the right, with Salt Meadow between.

the interlobate moraine, probably for some distance south of Manomet Hill (Plate XXXVI).

A large body of fresh water from the melting ice was thus held up between the morainal ridge and the ice-front in this reëntrant angle, forming a great glacial lake which will be treated of in this chapter of the present paper, and which I propose to name Lake Shaler in memory of the man whose name is indissolubly linked with the history of geologic science in New England.

The evidence in support of this hypothesis will now be given, beginning with a detailed description of the sand-plains already mentioned.

THE EASTHAM PLAINS

Leaving the moraine with its abundant boulders in the neighborhood of Orleans and passing northward to Eastham Centre, a low, flat region of till with some minor morainal deposits is traversed. From this point, to the end of the Cape, the boulders practically disappear, being found only in rare and quite isolated cases. From Eastham Centre, the tilly nature of the formation is succeeded by sandy plains more or less separated by deep valleys, the whole lower Cape to High Head, from which springs the Provincetown sand-spit (Plate XXVII), being composed of these plains, forming three and perhaps four distinct series at different levels (Figs. 9 and 10).

The Eastham Plains are comprised in the region between Eastham Centre and South Wellfleet. They rise from less than 60 feet in height in the south and west, to 75 feet and more in height in the east and north. They are fairly continuous along

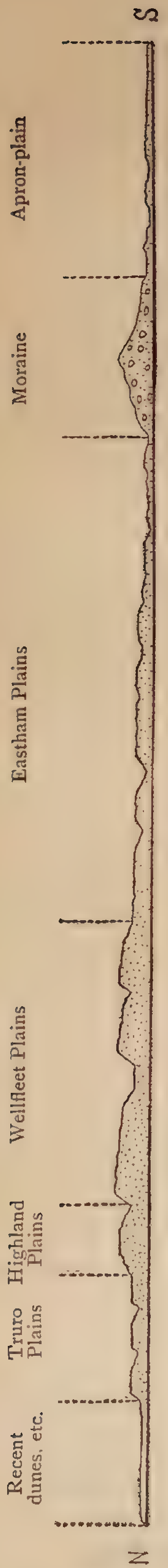


FIG. 9.

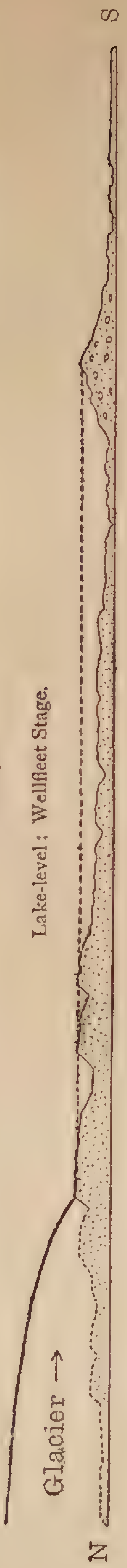


FIG. 10.

the eastern shore, but on the bay side are often isolated and disconnected, forming an irregular fringe. These plains, however, form one series, and are easily distinguished from the higher Wellfleet plains to the north, into which they pass somewhat abruptly, but by no such sharp line of demarcation as is exhibited between the Wellfleet and Truro plains, which will be considered further on. The individual plains of this series are separated by depressions having a general east and west direction, and occasionally by those having a north and south direction. The southern part of this area about Eastham Centre is much confused, and is filled with kettle and ice-block holes, many containing ponds. The northern portion, joining the Wellfleet plains, is often quite hummocky, and contains kettles and a number of points rising somewhat above the general level.

THE WELLFLEET PLAINS

The Wellfleet plains are much higher than the Eastham, attaining an elevation of about 140 feet above the sea. Thoreau mentions these plains as presenting a conspicuous elevation as seen from the sea, and says that they were known to sailors as the "table-lands of Eastham," being formerly included in that town. They commence in the higher levels to the east and south of Great Pond, and descend by gentle and irregular delta-like lobes to the lower plains. On account of the gentle and irregular slopes, the exact line of division between the two series is in places difficult to determine, but standing on the high ground immediately to the south of the Cahoon Hollow L. S. S.,[1] the lower levels of the Eastham plains are beautifully and clearly seen stretching away to the south.

These Wellfleet plains extend down the Cape as far as Highland Light on the east, and to within half a mile of North Truro village on the west. As in the Eastham series, numerous individual and disconnected plains appear on the bay side forming an irregular fringe, the elevation gradually increasing toward the east shore, where the series becomes more continuous. Depressions occur in a northwest and southeast direction, showing a contact-like slope on the southwest side, and a more gentle delta-like slope on the northeast; but very profound depressions traverse the region from northeast to southwest, generally exhibiting the characteristic arrangement of slopes, the steeper to the southeast, and the more gentle to the northwest (Figs. 9, 10, 11, and 12). The most remarkable of these is the valley of Pamet River, which passes

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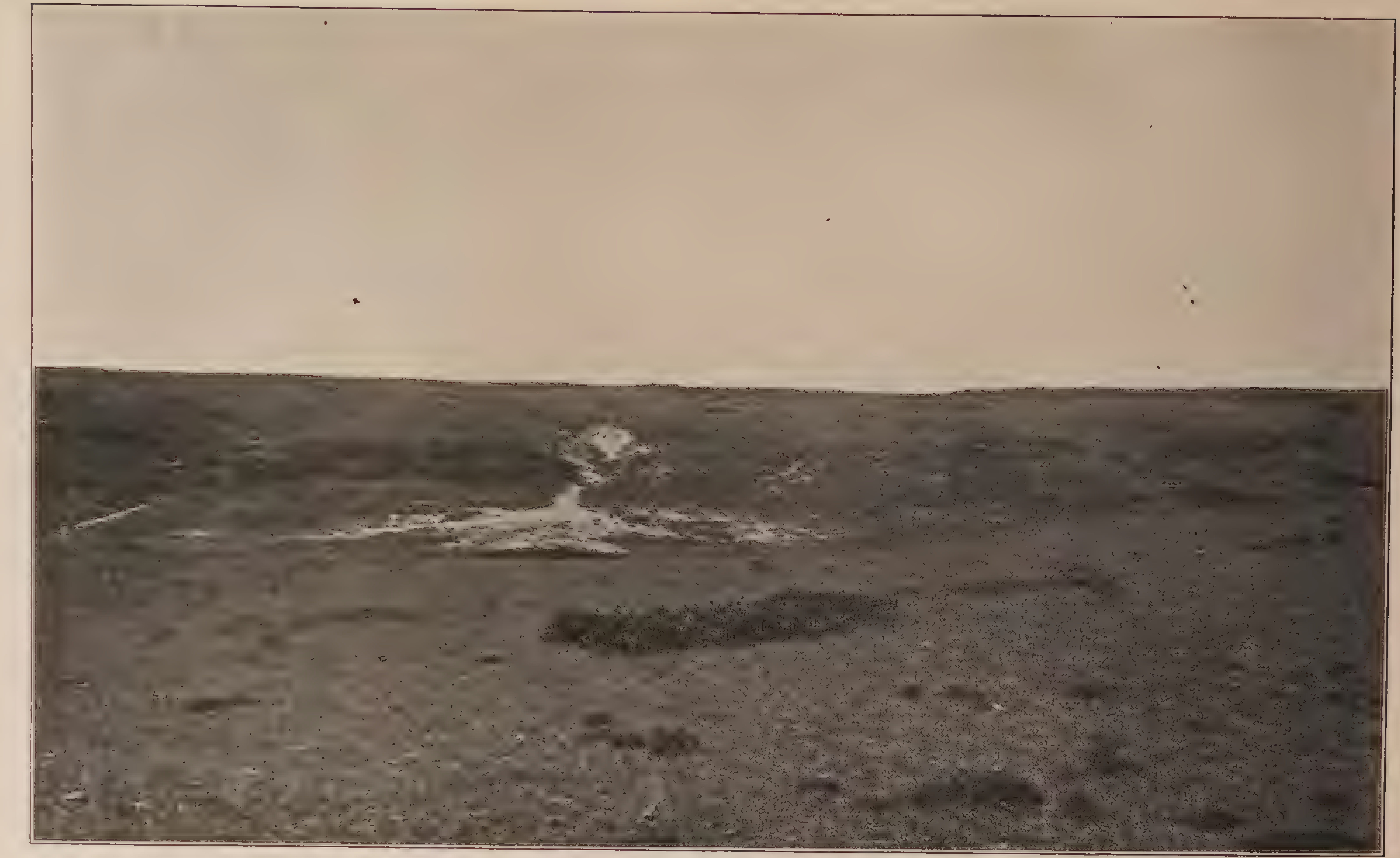
[1] This station is erroneously placed on the topographic sheet, being in reality about one mile farther south.



Wellfleet Plains from Highlands, looking Southeast.

Showing straight skyline.

PLATE XXIX.

Truro Plains from Highlands, looking Northwest.

almost entirely across the Cape at about sea-level. Others occur especially to the north in the neighborhood of Small's Hill, and are utilized for roads, being natural passes from shore to shore. These depressions and their peculiarities as valleys will be discussed later on. Numerous kettle ponds occur in the southern portion of the area south of Pamet River to the border of the Eastham plains east of Wellfleet village.

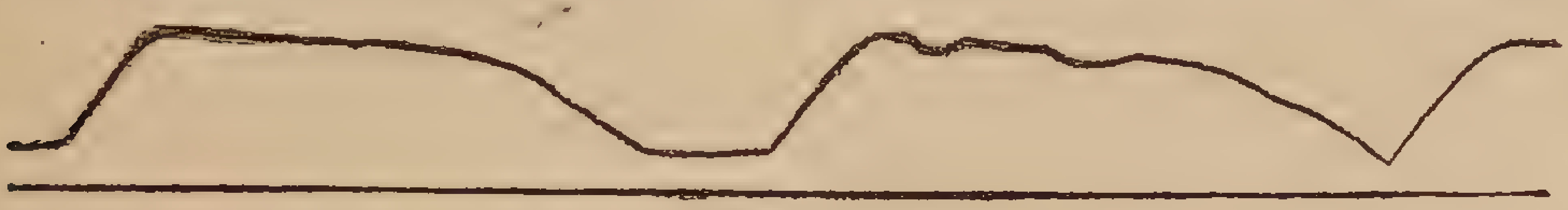


FIG. 11.

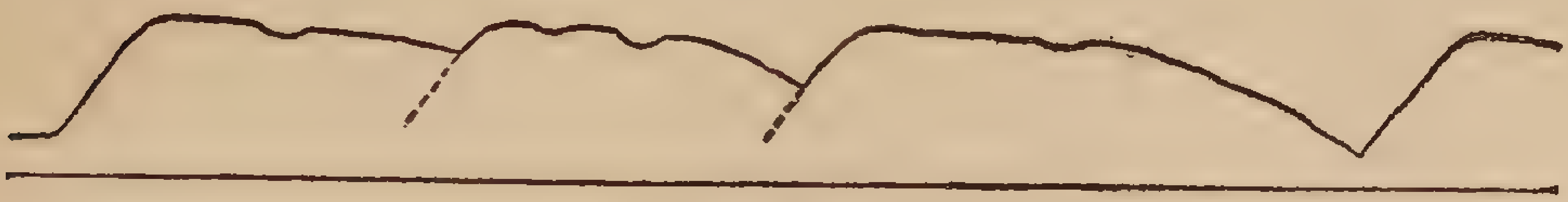


FIG. 12.

The surface of these plains is often very irregular, hummocky, and pitted with kettles; but the sky-line seen from one of the divides is remarkably straight and uniform (Plate XXVIII).

THE HIGHLAND PLAINS

These plains are the small group at Highland Light, and are so limited in extent that much further cutting back by the sea will make it necessary for the removal of the lighthouse tower to a position farther south on the typical Wellfleet plains; but there are considerations which seem to make it advisable to regard these plains as a separate series. They are at a lower level than the neighboring portion of the Wellfleet plains, being 125 feet above sea-level, and are separated from the latter plains by the striking contact-like slope which, passing almost entirely across the Cape, forms the northern boundary of the Wellfleet plains. They seem to be a remnant of a small intermediate series between the Wellfleet and Truro plains, the latter joining directly on to the Wellfleet plains with terrace-like effect just south of North Truro village.

THE TRURO PLAINS

The Truro plains extend from the Wellfleet and Highland plains on the south and southeast to the end of the mainland of the Cape at High Head, and have a quite uniform elevation of 80 feet above sea-level, diminishing somewhat in altitude towards High Head (Plate XXIX). Like the other series of plains, they are more continuous on the east, and more broken and separated on the west, part of the village of North

Truro and the turnpike to the south lying in one of the broad, flat-bottomed depressions between two plains of this series. Gentle northwest and southeast depressions occur, with more profound northeast and southwest ones, showing the characteristic contact and delta slopes oriented as in cases already considered.

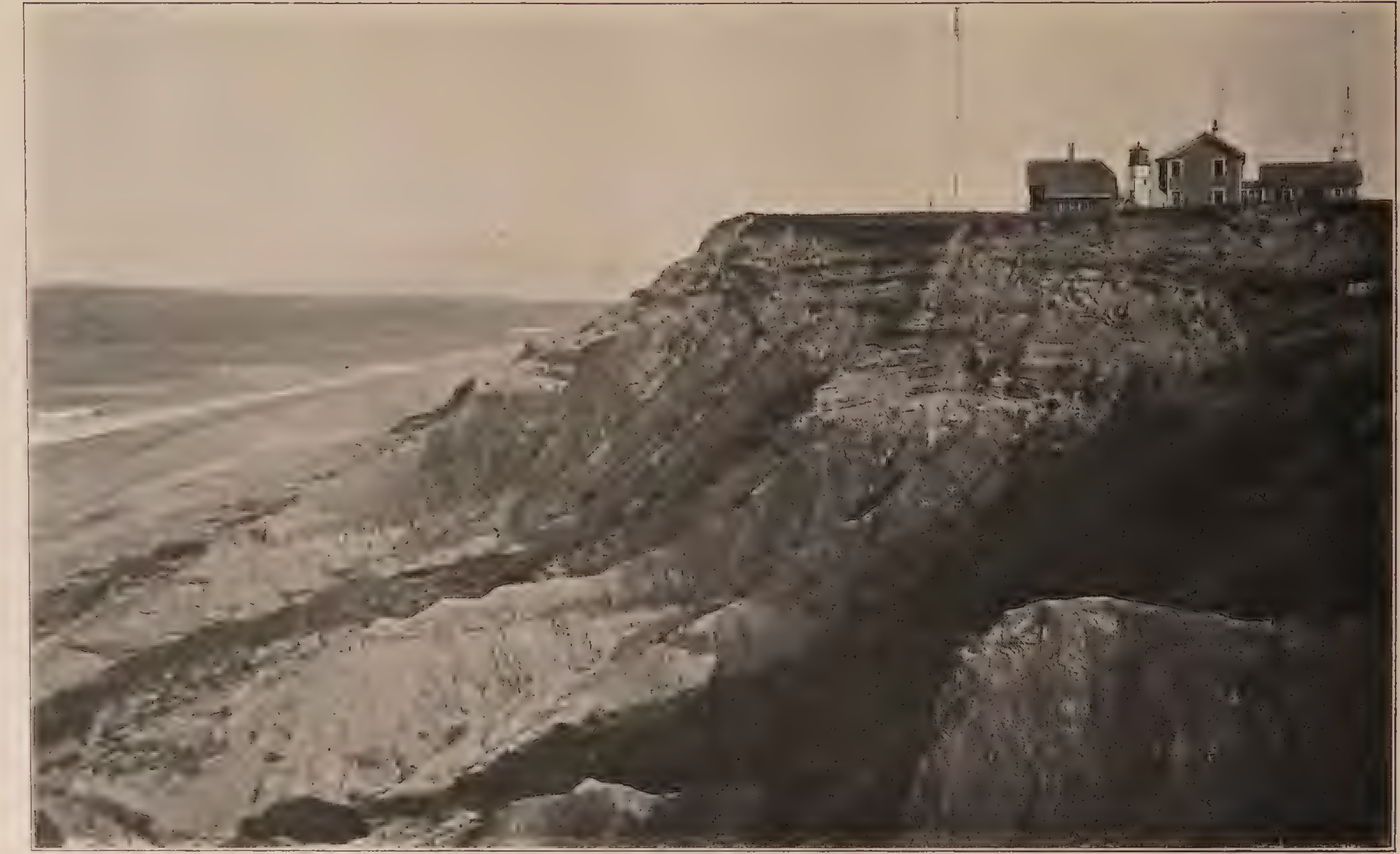
These plains are separated from the Wellfleet series by a very sharp line of demarcation. The Wellfleet plains descend, by the steep contact slope previously mentioned, into a deep valley, which extends from the bluffs on the east, separating the Highland plains from this series, to the broad, flat-bottomed depression mentioned above, in which lies the Provincetown turnpike. From this valley rise the more gentle delta-like lobes of the Truro plains, but as these plains do not attain to within 60 feet of the elevation of the Wellfleet plains, the latter, seen from the lower levels and bounded by the steep contact-like slope, present a very remarkable and striking escarpment (Plate XXVIII). At one point already mentioned, just south of the village, a small portion of the lower plains is separated by this valley, joining directly on to the contact slope of the higher plains. From the highway which passes from the lower series at this point, the terrace effect produced is plainly seen.

STRUCTURE AND COMPOSITION OF PLAINS

As has been mentioned, very few sections are presented for observation, and these, while they show the nature of the material, are generally so situated or so obscured by talus as to render an exact determination of the complete structure and sequence of the deposits almost impossible. There has been practically no postglacial erosion except along the shores, where steep bluffs have been produced. Along the ocean side this erosion has been considerable, but the loose nature of the material has resulted in the natural section thus exposed being more or less obscured by talus. One of the best sections is that at Highlands, where in places it is fairly possible to determine the general nature of the different layers from the top to the bottom of the bluff. The appearance of the bluff at this point is shown in Plate XXX.

About midway of the section is a lens-like mass of clay 40 feet or so in thickness, which seems to thin out and disappear in passing a few hundred yards either way along the shore. This clay is drab-colored and horizontally laminated. Some of the laminæ show the presence of grains of fine sand between the faces as if the result of settling in rather still waters. As well as can be determined, the clay shows an eroded upper surface, producing an unconformity between it and the

PLATE XXX.



Bluff at Highlands.

overlying stratified sands. This is shown in the plate, the sands, although generally horizontal in their bedding, having their lower portion at different elevations on the irregular surface of the clay.

A superficial examination shows no apparent difference between the deposits above and those below the clay. In both cases they consist of strongly cross-bedded and irregularly stratified sands and gravels, varying from fine sands to coarse pebbles up to 1 foot 6 inches or more in diameter, or approaching small boulders or boulderets. The stratification is always sharp and distinct, and the pebbles much water-worn. Many of the pebbly layers, especially below the clay, are strongly ferruginous, numerous pebbles being glazed and coated by a heavy oxide of iron. These pebbles seem to be glacial in their origin, and are apparently of the same nature as the surface drift. One rock in particular, a bright or dark red shaly limestone, which is very abundant on the surface, seems to be identical with the material of certain pebbles found in equal abundance below the clay. Although no fossils were found, there seems no doubt that this is the Cambric limestone already reported from this locality.

The last few feet at the top of the section consists of fine yellowish brown, micaceous sands, horizontally stratified and free from cross-bedding.

In the descent from the Highland to the Truro plains, the clay is reached, and its presence is shown in the rolling nature of the surface, descending gradually to the Truro level, and in the nature of the soil. Clay pits which are worked for the roads also reveal its presence at the surface.

I am of the opinion that both the upper and lower gravels are glacial deposits, and belong to the same period, that succeeding the Cape Cod stage, and that the lens-like mass of laminated clay was deposited in still water in front of a growing sand-plain in the manner shown by Fuller ('99), the plain eventually building out over it. Where similar clays are known to exist at other places, in this part of the Cape, they have no doubt originated in a similar manner.

VALLEYS AND KETTLES

The valleys and elongate depressions in the area under consideration, whatever their direction, present, as has been shown, in almost every case the same peculiarities of slope. In the case of the east and west, or northeast and southwest, valleys which extend crosswise of the Cape, the steep slope is found on the south or southeast, and the more gentle slope on the north or northwest. In the case of the depressions more or less at right angles to these, the steep slope is presented on the west or southwest, and the more gentle one on the east or northeast. This peculiar arrangement of slopes is found and maintained throughout the different series of plains, with the exception perhaps of the Eastham plains, where the case is not so clear.

There is no doubt that some of the valleys at least are valleys of construction due to glacial deposits, or are modified by glacial action, as they present in places kettle-like depressions. It seems certain, however, that practically all the valleys owe their origin to glacial construction, and are not due to erosion as in ordinary cases. This fact becomes more apparent when the following peculiarities are taken into consideration: —

1. The peculiar arrangement of the valleys in a more or less north and south and east and west direction, the cross valleys joining two parallel valleys in some cases, which can hardly be reconciled with the development of any known drainage system.

2. The constant presence of the steep and gentle slopes, their orientation, and the constancy with which they keep to their respective positions, not only in the case of a single valley, but throughout the whole series. Valleys of erosion degraded in soft and homogeneous material such as sand and gravel would certainly not present this peculiarity in scores of cases throughout this whole area.

3. The fact that the side of the valley presenting the gentle slope is generally more or less lobate, the lobes protruding into the valley at right angles to its direction in a manner which precludes the possibility of that side of the valley at least being due to the degrading effect of a stream passing down the valley.

4. The fact that a number of the valleys, as that of Pamet River, pass nearly if not quite across the Cape, are broad and flat-floored, with very little descent throughout their length, maintaining their width, and nearly their depth, to their eastward extremity. They consequently present in these peculiarities characteristics of old valleys, or the older lower reaches of valleys, and are too profound and well developed to result from a drainage system unless much greater in extent than that generally accredited to the old land surface of this region (Davis, '96).

5. The peculiarity that the divides between the valleys in any one series of plains are practically of the same elevation. Numerous kettles and kettle-like depressions occur; where these are crowded, the region has a hummocky appearance; but where the depressions are sufficiently separated, the divides appear as level plains, with perhaps a gentle slope to the southwest, terminating in a delta-like slope or lobes in one of the valleys or depressions.

To an observer standing on one of the divides, the area visible, although traversed by deep valleys and the surface broken by numerous large and deep kettles, presents the appearance of a continous level plain as is shown in Plates XXVIII, XXIX, XXXI.

The presence of numerous kettles, in places profoundly pitting the surface, with the other peculiarities mentioned, especially the different series of levels, seems to preclude the possibility of the region being an original plateau subjected to subsequent erosion and dissection.

The kettles present some peculiarities which need to be pointed out. Some of these depressions are true kettles formed by the melting out of a detached ice-mass, others again, generally more or less elongate, are portions of these constructional valleys cut off by lobes of the succeeding plain building out across the depression which, if the hypothesis is correct, is in reality a fosse to the preceding contact slope. These depressions show the characteristic slopes with the same relative positions as in the case of the valleys, and are undoubtedly of the same origin (Figs. 11 and 12).

When the kettles are close together, the dividing ridge may be sharp and sag below the general level of the plains, the kettles being too close to furnish the divide with a base sufficient to support it to its full height; but where the kettles are separated sufficiently, the divide rises to the same height, and is flat-topped like the plains, being in fact a portion of the plain between the kettles.

Accepting the hypothesis that these plains are in the nature of glacial sand-plains formed in front of the ice-sheet in a body of standing water, the nature and extent of which will be considered later, it must be remembered that after the first plains were formed the succeeding ones were deposited in the often constricted space between the ice-front and the plains already formed. This area must have been often obstructed by floating and grounded ice, over and around which the developing plain was formed. Thus from the constricted area, and blocking by ice-masses, strong currents must have been produced in the area of the forming plain by the streams from the ice-front, making the static condition of this portion of the water body merely nominal. These strong currents would account for the cross-bedded and irregular stratification, as shown in such sections as at Highlands, and also the eroded surface of the clay upon which the upper gravels were deposited. The absence in the few sections available for study of the typical foreset and topset structure of normal delta deposits seems readily explainable as a result of the above-mentioned conditions. In reality what might be called a backset structure could be developed as a result of a retreat of the ice as the plain developed. The plain thus unsupported would have a tendency to sag toward the ice-front, producing a structure directly opposite to the foreset beds expected.

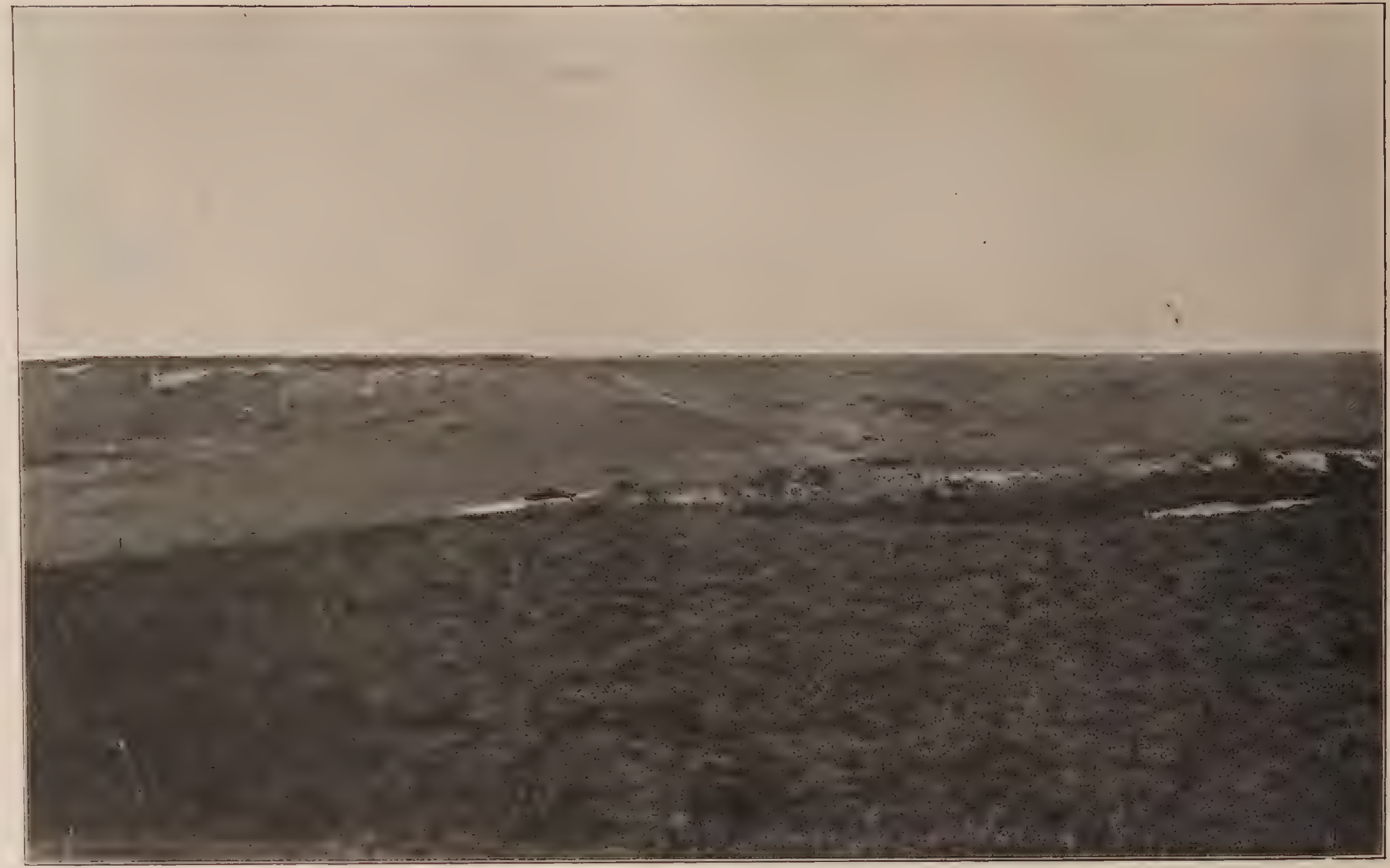
If this typical delta structure is developed, it should be in the first formed plains of any series, those detached plains forming the fringe on the bay side of the region, the plains on the ocean side, as has been mentioned, being closely joined and almost continuous. In some cases, it is most likely that such large ice-blocks were left in the fosse by the retreating glacier, that they remained until reached by the lobate front of the growing plain, destroying the lobate shape of the delta-front, and forming a contact slope in certain places on the delta side of the depression. The eventual melting out of the blocks buried in the plains would, of course, produce the kettles and hummocky appearance found so frequently throughout the region. There is abundant evidence that detached ice-masses occurred and produced the effects stated, as indeed was to be expected, and the presence of these ice-blocks would seem to afford ample explanation of any disturbance of, or departure from, a more normal sand-plain topography at any point.

There seems then, in my opinion, no reason to doubt that the formations under consideration are in their nature essentially sand-plains, deposited in a body of nominally static water in front of the retreating ice. These sand-plains are of course deposited upon an older formation, which was probably at one time an old land surface, and this may in places rise above the present sea-level, but such sections as are exposed and have been examined exhibit to their bases near sea-level the same cross-bedded sands and gravels, varying from quite fine sands to very coarse pebbles up to 1 foot 6 inches or more in diameter.

It remains then to consider the nature and extent of the body of water in which these plains were formed, with the land and ice-masses against which it was held.

The evidence furnished by Nantucket, as already set forth in the first part of this paper, shows conclusively that that region has not varied in elevation more than a few feet, at least in respect to the present sea-level, from the time the Wisconsin glacier finally withdrew its front from its position on the Nantucket moraine to the present day. This being the case, it is hardly reasonable to suppose that there has been any great submergence or uplift of an area so closely adjacent as that portion of Cape Cod under consideration. The sand-plains of Eastham, Wellfleet, Highland, and Truro, attaining as they do an elevation of from 60 or 75 feet to 140 feet above sea-level, could not have been formed in the sea or any bay or inlet connecting with it. They must therefore have been deposited in a body of ponded water, and this body, as will hereafter be shown, occupied in a general way the present

PLATE XXXI.



Truro Plains, looking Northwest across a Fosse.

Showing straight skyline.

area of Cape Cod Bay, and for which I have proposed the name Lake Shaler.

If a map of North America is taken, showing the position and extent of the last ice-sheet, the very irregular nature of its margin with protruding lobes and curved reëntrants is seen at a glance. It will also readily be seen that a retreat of the ice in the Cape Cod Bay region sufficient only to form one of the most minor and insignificant of these reëntrants, while it still held on to the moraine to the east and west, would necessarily cause the ponding of the water coming from the glacial streams between the high moraine to the south, and the bay-like recession in the ice-front to the north.

The melting back of that portion of the ice-front which still held on to the moraine exposing passes or cols across the moraine at lower and lower levels, would have the effect of lowering the level of Lake Shaler by successively making available outlets at lower levels for the discharge of the surplus waters. This being true, and the hypothesis correct, we should expect to find in the moraine an elevation sufficient to maintain the water at the high level of the Wellfleet plains, with passes or lower places in the ridge corresponding to the elevation of the different series of plains, these outlets also so related in respect to the ice movement as to correspond to the observed sequence of the different series.

THE MORAINAL DAM

A study of the topographic maps of the region from Monument River eastward to Orleans is most instructive, and reveals some interesting facts in regard to the problem under discussion.

From Monument River eastward to the neighborhood of East Sandwich, the morainal ridge attains an average elevation above the 200-foot contour; at only one point, immediately to the west of Bourne's Hill, does it drop below this level, and here the minimum elevation is between 160 and 180 feet. Eastward of Bourne's Hill it never attains the 200-foot level, except in Shoot Flying Hill and a few other small elevations in the township of Barnstable.

It first sinks to the 140-foot level corresponding to the Wellfleet plains in about two and one-half miles of its length, beginning at a point about two miles a little south of west from the West Barnstable station, and extending eastward to a point a little more than a mile southeast from the same place, where it again rises to the 200-foot level in two of the knobs mentioned above. In this two and one-half miles there are one or two points which rise slightly above the 140-foot level, forming low divides between the passes. While all the passes do not quite attain the 140-foot level, they vary so slightly that if at one time outlets for water held up to the north of the moraine, they evidently represent one system, the higher coming into play perhaps at times of flood or before the lower passes had been cut down. These outlets, for convenience, will be referred to as the West Barnstable outlets.

Eastward of the two 200-foot knobs which lie just south of Steward's Pond, the ridge drops to the 125-foot level, which corresponds exactly with the Highland plains. This 125-foot level is maintained uniformly for over a mile, when it drops to the 80-foot level in a pass three-fourths of a mile south of Barnstable station.

This 125-foot level is immediately to the north of Great Pond, and will also for convenience be referred to as the Great Pond outlet, while this 80-foot pass will be designated the Barnstable outlet. From here, the moraine rises to above the 100-foot level, which elevation it maintains for two miles, where it again sinks to the 80-foot level in a pass one-half mile southwest of Yarmouth Port station. The 100-foot contour is again reached in a small elevation beyond which, for the distance of a mile, the ridge sinks to an elevation of from 60 to 80 feet, rising again above the 100-foot level in a double-topped hill one mile south of Yarmouth village. These last passes will be referred to as the Yarmouth outlets.

From this point eastward to Orleans there are so many low places in the moraine, especially the depression of Bass River, that the ice must be considered as holding on to the moraine here during the deposition of the several series of sand-plains with the exception of the lower or southern portion of the Eastham plains.

BEACHES

If water has been held up along the moraine for any considerable time, with a discharge through the passes or cols we have considered, it might be expected that some traces of beaches at the different levels would be found with evidence of the passage of streams of water through the passes to the lower levels of the apron-plain on the south. The morainal ridge throughout almost its entire length is covered with a thick growth of small oaks and pines, making investigation for these minor features difficult, but such evidence as has been obtainable will be now considered.

A careful search was made for beaches, but no satisfactory evidence of this nature was found, except in the immediate vicinity of the outlets, in which connection it will be considered later on. The failure to discover any good evidence of beaches has only a negative bearing on the question, and may be due to the following causes:—

(1) The probably very short time during which Lake Shaler existed, an individual plain being formed perhaps in a single season (Fuller, '99). Of this total length of time one-third would probably roughly represent the maximum available for the cutting of any beach, as there are, as we have seen, four distinct series of plains formed during three stages, and corresponding levels of the lake. It is probable also that there was a certain amount of fluctuation of level of the waters, even during the particular stage marking the formation of one of the series of plains, due to times of flood and low water, and the probable choking of the outlets at times by ice jams. These fluctuations of level would be detrimental to the development of distinct beaches. (2) The absence of wave action, another and most important factor in accounting for the failure to find beaches at the different levels at which the ponded waters stood. It is most probable that a body of water such as that under consideration, held up by the moraine in front, in a reëntrant angle of an ice-sheet that had begun to break up in its final retreat from the region, was almost at all times covered by floating ice, so as to make it impossible for the development of waves of any considerable energy. The stranding of bergs and ice-blocks along the shore lines would also interfere with the action of any waves which might be present.

OUTLETS

The outlets, however, furnish more positive evidence as to the presence and discharge of waters ponded to the north of the moraine.

All the passes mentioned corresponding in elevation to the different series of plains were carefully examined, and were found to present in every case the general features shown in Fig. 13. These outlets exhibit fairly broad, flat floors, with generally a slightly deeper channel in the centre, probably the outlet at times of low water. As seen by the figure, the floor or sill over which the water passed is bounded on each side by a rather abrupt slope, which in some cases can be traced for a short distance on the north side of the outlet, as a sort of beach line. The floor or sill in each case examined shows rather fine sand on the surface, but in two cases, wood roads were discovered which led to the foot of the steep bounding slopes for the purpose of obtaining boulders, which

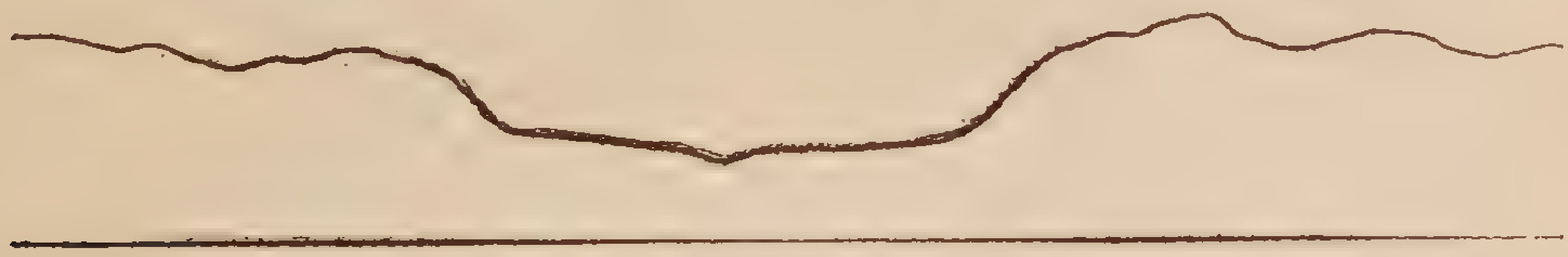


FIG. 13.

were especially abundant at or near the surface in these localities. I am of the opinion that the underlying clay, the top of the anticlinal fold, is reached in the floor of these outlets, and masked by a small amount of sand, as otherwise the cols would have soon been cut to the base of the ridge. This fact is also shown by the presence of swampy places in or in the immediate vicinity of the cols.

From these outlets on the south side, ravines communicate in each case, as a study of the topographic sheets will show, with valleys, ponds, or chains of ponds which indicate the former presence of streams of water. Of course, at the time the moraine was formed, streams coming from the ice-front flowed down on to the apron-plain, so that it is perhaps impossible to distinguish between the features resulting from streams coming from the discharge of the ponded waters and those which preceded them from the ice-front.

It must not be forgotten that during the existence of Lake Shaler, that while the Long Island lobe may have begun its retreat from the Elizabeth Islands, it continued to fill Buzzard's Bay, pressing against the interlobate moraine south of Monument River, and effectually closing that pass as an outlet for the ponded waters.

In view of all the evidence deduced, there seems to be no reason to doubt that our hypothesis is correct. The formations of Eastham, Wellfleet, Highlands, and Truro in the phenomena which they present, when thoroughly understood, leave no room to doubt that they are sand-plains formed in a body of ponded water, held up in a reëntrant angle of the retreating ice-front by the morainal ridge to the south. Indeed, there seems to be no other hypothesis at all adequate to explain their peculiarities, and when in addition we find the cols in the morainal ridge so exactly coinciding in elevation and order of succession with the several series of plains themselves, the proof of the hypothesis would seem to be ample.

The nature and extent of Lake Shaler through the different stages corresponding with the several series of plains will now be considered more in detail.

THE WELLFLEET STAGE

At the close of the Cape Cod stage of the Nantucket lobe, the ice began to melt back from the moraine somewhere between West Barnstable and Manomet Hill, its front still holding on to the east and west of those points. Fresh water from the glacial streams was thus enclosed between the moraine and the ice-front, and Lake Shaler began its existence as a glacial feature in this region.

The 140-foot West Barnstable outlets were thus exposed, while the low pass at Monument River was closed by the ice of the Long Island lobe in the Buzzard's Bay region. There is reason to suppose that this landward ice was much more persistent, effectually closing the Monument River pass, until or after the disappearance of Lake Shaler. As the ice melted back, and the lake grew in size, deposits were probably laid down between the free portion of the moraine and Wellfleet, which have since been eroded or are represented in some of the numerous shoals.

But the melting back was probably rapid, and no doubt along some extensive line of preëxisting glacial drainage. This old drainage line would explain the elongate nature of the lake formed, and be in accord with the northeast and southwest alignment of its axis, the ice-sheet and so also the glacial waters coming from a northeast direction. As an old higher land surface was reached in the neighborhood of Wellfleet, the deposits and sand-plains were built up to the level of the lake in the manner common to delta formations, while the successive retreats and haltings of the ice-front resulted in the formation of the multitudinous individual plains within a single series, any series being limited by the restriction of the discharge of the surplus waters to one set of outlets.

The choking of the channels, the building of a plain over and around detached ice-masses, and their subsequent melting out, with even slight readvances of the ice at any point, would amply account for any of the abnormal or otherwise puzzling features noticed.

A generalized outline of Lake Shaler and attendant features at the close of the Wellfleet stage is approximately shown in Plate XXXVI.

THE HIGHLAND STAGE

A short stage was now introduced which is represented by the formations of the small group of plains at Highlands. A slight retreat of the ice to the east of West Barnstable exposed the 125-foot Great Pond outlets, lowering the lake to that level.

At the same time, an insignificant melting back at Highlands allowed the formation of those plains at the lower level. It is probable that this was accompanied by a breaking up of the reëntrant ice-front in the neighborhood of South Wellfleet, and southwestward to Barnstable. Deposits or fragmentary plains were then laid down among the ice-masses, which would explain the inliers of higher levels in the northern part of what have been called the Eastham plains, and which will be considered further.

A generalized outline representing conditions and features during or at the close of this stage is shown in Plate XXXVII.

THE TRURO STAGE

A further retreat of the ice from the vicinity of Barnstable allowed the 80-foot Barnstable outlets to come into play, draining Lake Shaler down to that level. There was then a lowering of the waters, amounting to 45 feet, which, if sudden, would have been productive of a great rush of waters and strong currents among the detached ice-masses in the northern portion (formed during the Highland stage) of the Eastham plains. A great amount of material would be washed out and redeposited, the undisturbed remnants remaining as the higher level inliers noticed above.

During the retreat of the ice in this stage, the Truro plains were formed with strikingly uniform level (Plates XXIX and XXXI), and probably the more central portion of the Eastham plains. Before the last or northernmost of the Truro plains were formed, the ice lying against the moraine had probably exposed the Yarmouth 60-foot outlets, these later formed plains, not attaining quite the altitude of those adjoining the Highland and Wellfleet series. This stage is more or less generalized in Plate XXXVIII.

The lower or southern portion of the Eastham plains were undoubtedly the last formed in the final melting away of the ice, Lake Shaler persisting for some time at low levels, due to the choking by ice-blocks of the low valleys between Yarmouth and Orleans.

It might be thought that the several series of plains were formed successively from south to north by the gradual retreat of the ice. This would necessitate assuming, however, that the eastern lobe which held on to the moraine pushed energetically westward beyond Barnstable to Shoot Flying Hill, after the Eastham plains were formed, in order to close all the cols below the 140-foot level, which was necessary for the constitution of the Wellfleet stage.

By consulting Plate XXXVIII, it will be seen that energy which would push the ice so far as to close the lower outlets can hardly be reconciled with such a narrow tongue-like lobe as would lie between the moraine and the already formed Eastham plains, when the conditions in the region were for retreat rather than advance.

This interpretation would also not explain the presence of the higher inliers noticed in the northern part of the Eastham plains.

CHAPTER IX

AN ARGUMENT FOR A FOURTH CENTRE OF GLACIAL DISPERSION IN NORTH AMERICA

THE Cordilleran, the Keewatin, and the Labrador ice-sheets or centres of dispersion have long been recognized, and they are considered to be established beyond controversy. As my investigations have progressed I have become more and more firmly convinced that there was at this time a fourth in the region of which the present land mass of Newfoundland is the centre. The fourth sheet was one of such magnitude and activity that it sent a lobe of ice as far as Cape Cod and Nantucket. I am aware that this view is somewhat revolutionary, and has, as far as I know, never before been proposed; but it seems to be best in accord with all the facts which I have been able to gather in regard to the glacial geology of the Atlantic coast. It is, moreover, in striking agreement with some heretofore puzzling features.

The supposition is generally held that in early glacial times, and during the latter part of the period immediately preceding it, the northern part of the continent stood at considerably higher elevation. This elevation of the northern regions has been given by some as the cause of glaciation through increase of cold, and of precipitation in the form of snow. Upham shows (Upham, '96), that the Saguenay chasm was eroded by a preglacial stream to the maximum depth of 840 feet below the present sea-level and that it therefore indicates a preglacial elevation in that region of at least 1000 feet.

Dr. Grabau shows also (Grabau, '01, p. 49, Fig. 8), that the formation of the basin of Lake Ontario from a preglacial valley through tilting of the strata, demands a former elevation more than 2500 feet greater than that of the present day.

Le Conte mentions (Le Conte, '03, p. 582) an elevation of the northern portion of the continent in early glacial times of 1000 to 2000 feet above the present condition. Even much greater elevations are postulated by some geologists.

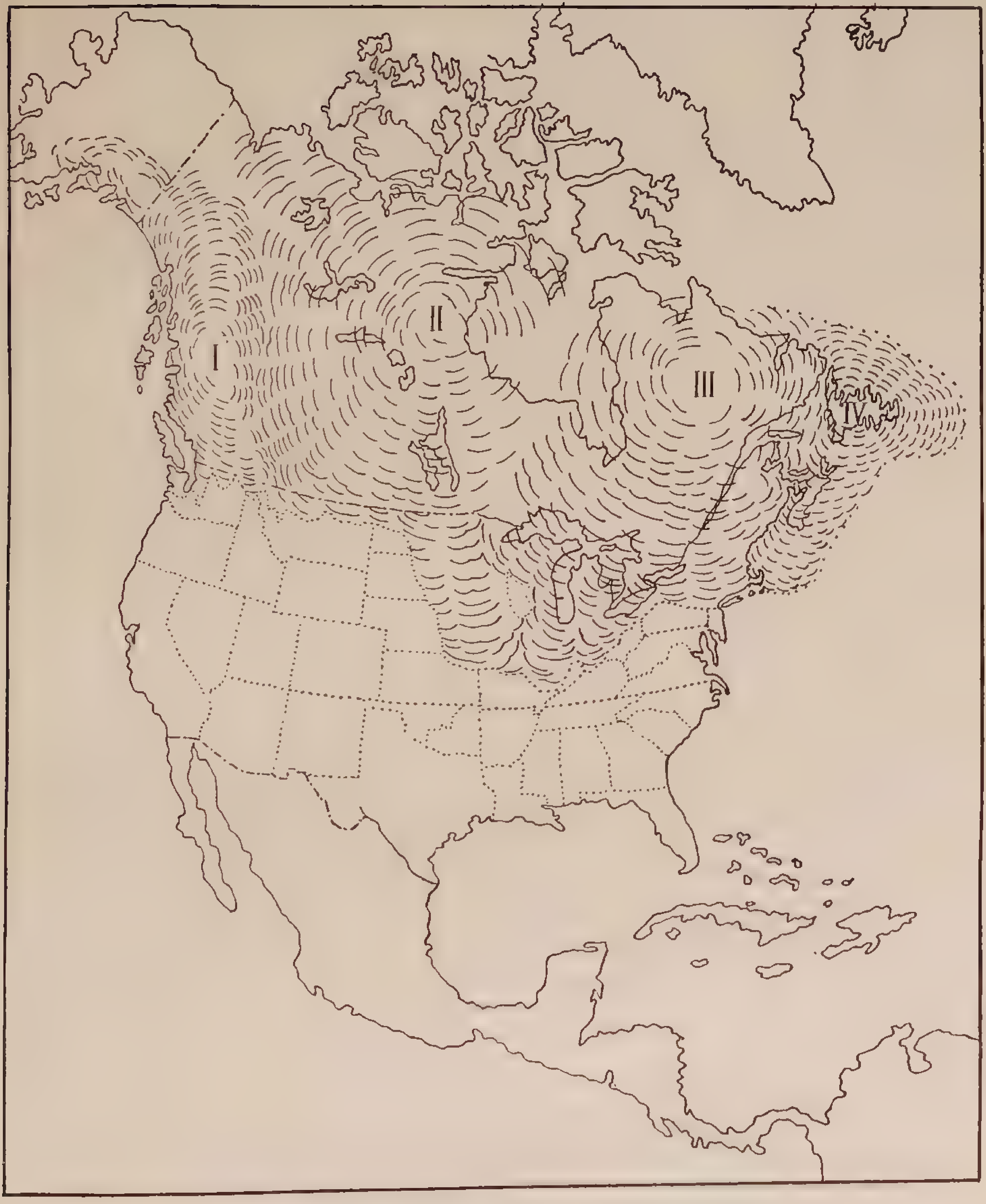
When the land stood higher in this northern region, all the Grand Banks, and in fact practically all the region to the continental shelf, with a large area to the south and west, was added to the present land-mass of Newfoundland, while the present area had its altitude increased by a thousand feet or more. A great ice-sheet here would no doubt have extended its lobes and glaciers to the continental shelf, where the ice would have broken up into bergs, while its extension westward would have been prevented by the massive ice coming from Labrador. But what concerns us most is whether a lobe originating in the Newfoundland area moved southwesterly through the Bay of Fundy into the Gulf of Maine, finally reaching as far as southeastern Massachusetts, and forming the moraines and glacial accumulations of Nantucket, of the eastern half of Martha's Vineyard, and during a retreatal stage those of Cape Cod. The facts at present available which seem to make this probable will now be given and briefly discussed under the following heads: —

1. Availability of the Newfoundland region for an ice-sheet of such magnitude, with evidence of great glaciation.
2. Direction of the ice movement along the Atlantic coast from Newfoundland to Nantucket.
3. The interlobate region.
4. Transported material.

1. *Availability of the Newfoundland region for an ice-sheet of such magnitude, with evidence of great glaciation.*

If we consider this region to have been elevated 1000 feet, and it may be that the more extreme views in regard to the elevation of the northern part of the continent in glacial times will be found to be nearer the truth than the more moderate, we would have all that portion of the sea bottom within the 1000-foot soundings added to the present area of Newfoundland as dry land. A glance at Plate XXXIII (differential elevation not being taken into account), will show that this would vastly increase the area for the support of an ice-sheet, while the same amount of elevation added to the present land surface would materially aid in its development, since the present high land in the western part of the island rises upwards of 2000 feet above sea-level.

Another factor of considerable importance is the position occupied by this land-mass with respect to the surrounding ocean. It will be noticed that it forms a great salient, surrounded by the ocean on the northeast, east, and south. It is thus more favorably situated for receiving the precipitation from moisture-laden ocean winds than any of the other great centres of dispersion. While this Newfoundland area may not be so large as the others, through this cause it may well have supported an ice-sheet of great activity.



Relation of the Four Centres of Dispersion.

The first three after Salisbury.

While the ice-sheet was developing on Newfoundland, great precipitation was probably taking place on Nova Scotia; the two ice-caps then coalesced, and there was in a sense an elongate ice-cap stretching along the coast, including the two regions, and receiving the precipitation from the moisture-laden winds from the sea, much as did the Cordilleran region on the Pacific coast.

The greater impulse would probably come from the northern and higher area, the ice of Nova Scotia adding to, but being directed by, the great mass on Newfoundland.

The extension of a lobe as far as Nantucket may seem a questionable feature where its length is compared with its width, as shown on the map; but it will also be seen that it is very comparable to that lobe of the Keewatin ice-sheet, which at one time existed west of the driftless area of Wisconsin: and while the latter as shown by the driftless area was a distinct narrow lobe unbounded by any distinctly higher land, the narrowness of the supposed Atlantic lobe was more apparent than real, as the limit of its extension seaward was simply due to the breaking up of the ice as bergs on the edge of the continental shelf. It may be objected that the Labrador ice would have pushed this Newfoundland lobe out to sea, unsupported as it was apparently on the seaward side, but it must be remembered that in the southern part of the region, the ice from Labrador had evidently nearly attained its maximum limit, while farther north, the depression of the Gulf of Maine and the great trough of the Bay of Fundy with higher land to the east, acted as a groove to hold in place the ice coming from Newfoundland. Still farther north, and nearer the centres of dispersion, the differential elevation furnished by the highlands of western Newfoundland, aided by the deep depression of the Gulf of St. Lawrence and its continuation northward in the Straits of Belle Isle to the west, would have furnished a barrier of no mean strength to the eastward movement of the Labrador ice. The basin of the Gulf once filled, the ice would become nearly stagnant, and of this condition we seem to have some evidence. Sir J. W. Dawson says (Dawson, '72, p. 207): "The older boulder-clay of Prince Edward Island with native boulders must have been produced under circumstances of powerful ice-action, in which comparatively little transport of material from a distance occurred. If we attribute this to a glacier, then as Prince Edward Island is merely a slightly raised portion of the bottom of the Gulf of St. Lawrence, this can have been no other than a gigantic mass of ice filling the whole basin of the gulf, and without any slope to give it movement except toward the centre of this great, though shallow, depression."

It might be further objected that the deep channel between Newfoundland and Cape Breton Island, lying across the path of ice moving toward New England, would have proved a serious obstruction. We must, however, remember that this channel (under the conditions then prevailing), although deep, would probably have become filled with ice, having little or no motion in its lower portions. This ice would have supported the main ice-mass, and offered less resistance to its passage than an irregular surface of rough rock.

In regard to the evidence of great glaciation of this region, much information is to be obtained from the work of Alexander Murray on the "Glaciation of Newfoundland" (Murray, '82–83). He points out (p. 57) that the great topographic features such as valleys and mountain ranges and the deep fiords have all a northeast and southwest alignment, which, as we shall see, is the direction of the principal grooves and scratches, as also the direction necessary for the latter if the ice moved from here to Cape Cod and Nantucket. Some of the northeast and southwest troughs contain lakes of enormous depths, Grand Pond having a depth of over 1100 feet, the deepest part being over 988 feet below sea-level. It seems to me hardly possible that these deep troughs owe all their depths to the gouging effect of the ice, but in view of other evidence, it seems probable that it may be attributed in part to this cause.

Murray speaks (p. 55) of "evidences of enormous pressure from moving masses passing over the surface," and says (p. 59): "Evidences of vast abrasion are abundantly displayed almost everywhere all over the island, by '*roche moutonnée*,' transported boulders, parallel grooves and scratches, and moraine rubbish. The rounded form of the hills is often very conspicuous; the Cape Anguille range is softly rounded to the summits, rising to 1860 feet at the highest points, while the hills beyond, as seen from a western point of view, rise in a series of rounded peaks or cone-shaped domes to various altitudes, many of which are over 1500 feet." He says also (p. 60): "Parallel grooves and scratches have been preserved on rock surfaces, capable of retaining such at all altitudes, from the sea-level to the height of a thousand feet, and perhaps more. The prevailing bearing, as a whole, of these markings is northeast and southwest or nearly so." He gives a table of striæ in Conception Bay, the directions being roughly northeast and southwest, although there are some variations from this. He says (p. 61), "At some parts, as at James's Point, in Collier's Bay, the grooves can be traced rising over its southwest slope to its summit, and on Burke's Point, which is a smooth and highly polished rock, a groove was observed 22 feet wide, and 20 inches deep, traceable for 70 feet." Murray quotes from observations of the late Captain Kerr, R.N., as follows: On Ladle

Island, in Sir Charles Hamilton's Sound, a groove 10 feet wide and 12 inches deep, with direction S. 73° E.; on One Tree Hill, west side of Poole's Harbor, Bonavista Bay, scratches bearing S. 66° E.; on Shoe Point, Bonavista Bay, scratches bearing S. 70° E.; on Lewes Island, Bonavista Bay, scratches S. 88° E.; on Fogo Island, surfaces ground, but ice marks obscure, apparently N. 15° E., the boulders apparently derived from the hills to the S. W., etc. On the parade ground above St. John's, striæ were observed by Murray on a smoothly polished surface of slate bearing N. 86° 30′ E. Numerous other cases are given, but these will suffice to show the general direction of the striæ as reported by Murray.

2. *Direction of the ice movement along the Atlantic coast from Newfoundland to Nantucket.*

As as been shown in the second chapter of this paper, the glacial phenomena in southeastern Massachusetts are the result of two district lobes, which I have called the "Long Island" and "Nantucket" lobes from the regions of their principal moraines. The ice of the Nantucket lobe occupied the region east of the northern point of Martha's Vineyard and the interlobate moraine which extends north from Wood's Hole to Manomet Hill near Plymouth. While we know that west of this moraine the ice came from a general northwest direction, facts revealed seem to show conclusively that to the east the motion of the ice was from the northeast with a far distant and entirely different source. The reasons for believing this will be briefly given.

1. The probable great extent seaward of the ice-sheet, the shoal water of the continental shelf offering no obstacle, with indications of this in the banks or shoals lying off the coast, and the great development of the ice-contact slope and kame hills on the extreme eastern part of Nantucket.

2. Considering in general that the motion of the ice was approximately at right angles to the front, the direction of the ice-front of this lobe, as shown by the moraines and contact slopes from the northern point of Martha's Vineyard to Tom Never's Head on the southeastern shore of Nantucket, where the ice-front passed out to sea, being southeasterly, would indicate a motion from the northeast.

3. The north and south direction of the interlobate moraine with contact slopes on both sides, the ice being known to have come from the northwest on the west side, indicates that eastward the motion was from the northeast.

4. It was found that "Lake Shaler," described in the last chapter

formed at the time of the melting back of the ice from the Cape Cod position, probably along a line of weakness resulting from subglacial channels and drainage, was an elongate body of water, its axis having a northeast and southwest direction.

Assuming that the ice of the Nantucket lobe did come from the northeast, if it were part of the Labrador ice-sheet, it must have been some part moving seaward north of the interlobate moraine. As we shall see, the interlobate conditions can apparently be traced as far north as Cape Ann, making it necessary for the Nantucket lobe to have moved seaward from some region still farther up the coast. This would necessitate the presence of some barrier lying out to sea, of which we have no knowledge, able to turn the ice against itself at an angle of 90°, and cause it to move southwesterly to Nantucket, and would not explain the nature of the morainal material. Even if Cape Ann were excluded as part of the interlobate region, these difficulties would not be removed.

If, however, we continue still farther to the northeast, we come to Nova Scotia and the Bay of Fundy, and eventually to Newfoundland; and if our hypothesis is true that the Nantucket lobe had its origin here, the facts obtainable in this region should bear some testimony. Such facts as I have been able to gather in regard to the motion of the ice in this region will now be given.

Dr. G. F. Matthew writes me that in southeastern New Brunswick and along the Bay of Fundy the ice motion was to the southwest, but he apparently attributes this direction to local causes, such as the slopes of valleys, and the slope toward the deep water at the mouth of the Bay of Fundy.

Professor H. Y. Hind ('65, p. 183) mentions striæ at St. John as having a direction N. 30° E., and others at South Bay, N. 25° E.

Sir J. W. Dawson says (Dawson, '68, p. 60): "To the southward and eastward of the Cobequids, throughout Colchester, Northern Hants, and Pictou, fragments from these hills [Cobequid], usually much rounded, are the most abundant travelled boulders, showing that there has been great driftage from this elevated tract. In like manner, the long ridge of trap rocks extending from Cape Blomidon to Brier Island has sent off great quantities of boulders across the sandstone valley which bounds it on the south, and up the slopes of the slate and granite hills to the southward of this valley." And also (p. 61), "A very large proportion of the present features of the surface indeed result from this cause [glacial action]; the ridges of Cumberland, the deep valley of Cornwallis and Annapolis, the great gorges crossing the Cobequid Mountains, and the western end of the North Mountains in Annapolis and Digby counties, such eminences as the Green Hill in Pictou County, and

Onslow Mountain in Colchester, are due in great part to the removal of soft rocks by denuding agencies of this period, while the harder rocks remained in projecting ridges." He shows the striæ to be generally southerly and southeasterly in the southern part of Nova Scotia, indicating a fanning of the ice.

Professor L. W. Bailey ('90–91, p. 5) also mentions that the striæ in Queens and Shelburne counties in the southern part of Nova Scotia indicate a fanning of the ice to the southwest and around to the southeast and says (p. 3) that granite boulders are found widely removed from any known outcrop of similar rocks.

Professor A. E. Coldwell writes (Coldwell, '95–96, p. 173). "I have also found [near Wolfville] small boulders of syenite and diorite, which must have come from the Cobequid Mountains, as they resemble the rocks found in that range, and are unlike any country rock I have seen on this side of the Minas Basin." He mentions some glacial scratches as having a southeasterly trend.

H. S. Poole gives some interesting facts in regard to the Pictou region from which I quote (Poole, '90–'94, p. 232): "That the set of the drift was from the southwest is assumed from the direction of the surface ridges and from the course of the principal series of striæ on the rocky surfaces. There is a good exposure on Weaver's Mountain, N. 45° E. Another on the southern base of the highest peak of McLellan's Mountain overlooking the Marsh, N. 42° E. Also at Pictou, N. 55° E., and again at the Fox Brook schoolhouse. The form, too, of the peak on the range of McLellan's Mountain, close to the brook of the same name, suggests a similar conclusion. Viewed from the southwest, it appears conical with steep slopes, while on its northeast side it is backed up with talus of considerable magnitude."

If we translate this drift "from the southwest" to toward the southwest, we have a direction of motion here exactly fulfilling the requirement of the hypothesis.

As seen by the map we might expect a southerly and even southeasterly motion along the southeastern shore of Nova Scotia, especially after the period of maximum glaciation. For movements of the ice in Nova Scotia, as elsewhere in the region under consideration, when they differ considerably from the direction to be expected, but are local, may be explained by the driftage from high lands when the main ice-sheet was passing away.

In regard to Prince Edward Island, which is another link in the chain leading to Newfoundland, Sir J. W. Dawson furnishes some interesting facts, as follows (Dawson, '72): "Superficial deposits consist of boulder-clay, stratified sand and gravel, and loose travelled boulders. Boulders in the 'boulder-loam' are almost universally of the native rock (Triassic sandstone), and must have been produced by the grinding of ice on the outcrops of the harder beds. In the eastern and middle portion of the island, only these native rocks were seen in the clay, with the exception of pebbles of quartzite which may have been derived from the Triassic conglomerates. At Campbelton, in the western part of the island, I observed a bed of boulder-clay filled with boulders of metamorphic rocks similar to those of the mainland of New Brunswick.

"Striæ were seen only in one place on the northeastern coast, and at another on the southwestern. In the former case, their direction was nearly southwest and northeast. In the latter it was S. 70° E.

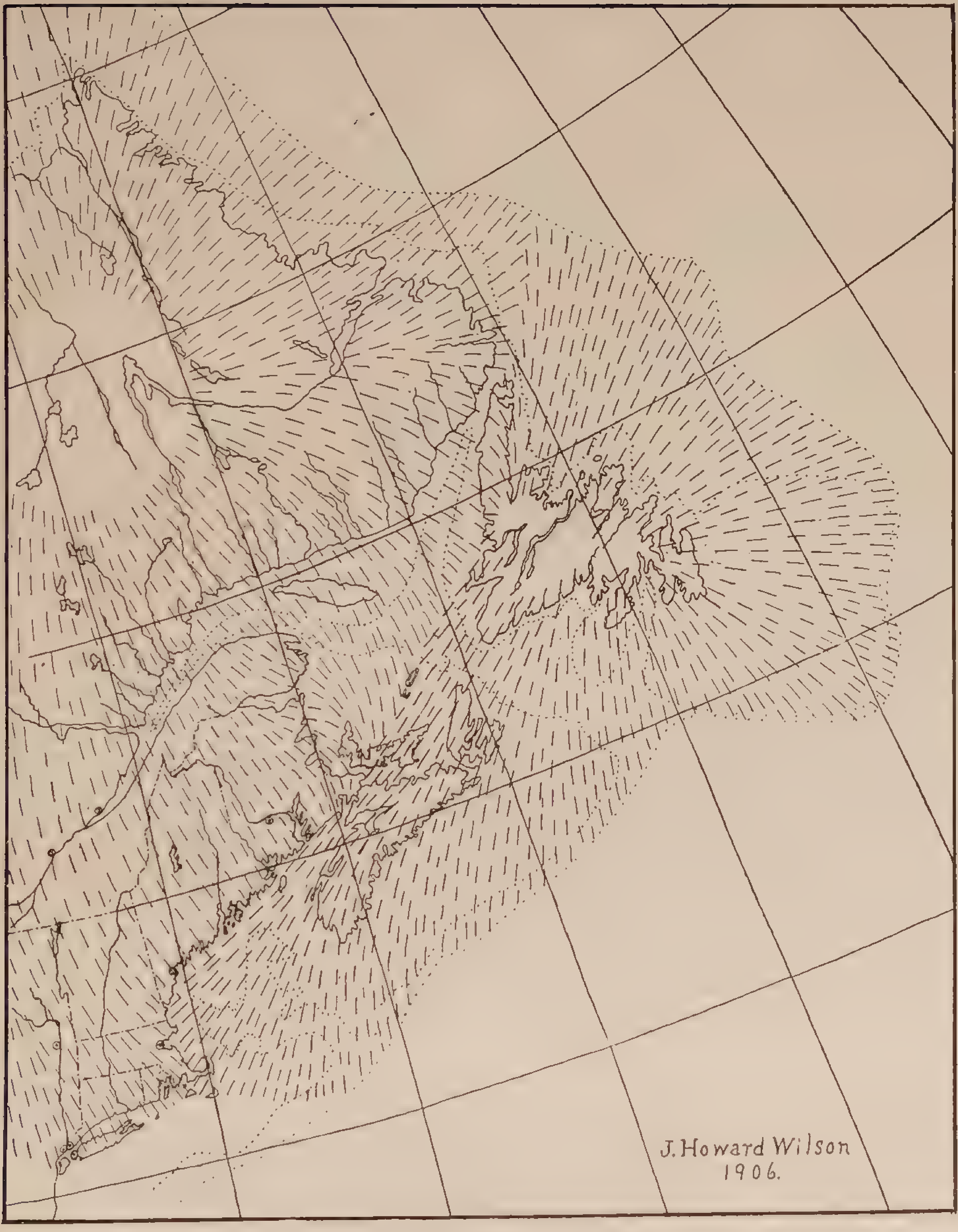
"On the surface of the country, more especially in the western part of the island, there are numerous travelled boulders, sometimes of considerable size. As these do not appear *in situ* in the boulder-clay, they may be supposed to belong to a second or newer boulder-drift. . . .

"These are foreign to Prince Edward Island, and are granite, syenite, diorite, felsite, porphyry, quartzite, and coarse slates, similar to the metamorphic districts of Nova Scotia and New Brunswick; some may have come from Cape Breton. It is to be further observed that these boulders are most abundant, and the evidences of denudation of the Trias greatest, in that part of the island which is opposite the deep break between the hills of Nova Scotia and New Brunswick, occupied by the Bay of Fundy, Chignecto Bay, and the low country extending thence to Northumberland Strait, an evidence that this boulder-drift was connected with currents of water passing up this depression from the south and southwest." Dawson also mentions rocks on the north side of the island which he says seem to have come from Labrador. The striæ on the eastern end of the island point toward Newfoundland and the trough between Nova Scotia and New Brunswick which is continued in the Bay of Fundy, while those on the western end indicate a certain amount of feeding of the ice from Labrador and eastern New Brunswick into this same trough. This is shown on Plate XXXIII. The denudation of that part of the island lying opposite this trough, and consequently in the path of ice moving from Newfoundland to the Bay of Fundy, seems of special significance.

Cape Breton Island, still nearer to Newfoundland, furnishes some facts which have been revealed by the work of different explorers. The more pertinent of these may be given.

Charles Robb makes the statement (Robb, '74–75, p. 264): ". . . numerous parallel bays and channels in the coast as well as ridges in the interior, which are probably due to glacial action. This is indicated by their general direction, being coincident with that of the glacial striæ

PLATE XXXIII.



The Newfoundland Ice-sheet.

of which numerous reliable observations were obtained. The occurrence also at the head of the northwest arm of Sydney Harbor, of a great profusion of erratic boulders, consisting of granitic, felsitic, and hornblendic rocks, probably derived from remote northern regions, and the manner of their distribution, seem also to confirm this supposition. It is worthy of remark that the distribution of the hard metamorphic rocks appears to have influenced the direction of the denuding agencies during the glacial period. Thus it would seem as if the entire area of Bras d'Or Lake has been excavated by glacial action in the soft marls and other friable rocks of the Lower Carboniferous formations, the remains of which now fringe its margin. Glacial striæ were observed at several points throughout the region, both on the highest crests of the ridge, and also to the sea-level, but only on the millstone grit rocks." He gives list of localities and directions of striæ, a partial list of which are here given:—

Indian Cove, Sydney Harbor, north side, S. 61° W.

Victoria mines wharf, Sydney Harbor, south side, S. 54° W.

International wharf, Sydney Harbor, south side, S. 52° W.

Cow Bay road, halfway between Sydney and Cow Bay, two sets crossing S. 76° W. and S. 36° W.

Cow Bay road, one mile west of the last point, S. 54° W., and numerous others with similar directions (p. 265).

Mr. Hugh Fletcher gives similar evidence (Fletcher, '75-76), and says (Fletcher, '76-77, p. 449), "Glacial striæ were seen on the St. Peter's road near Gillis Mill, East Bay [Great Bras d'Or Lake], running S. 64° W.," and also (Fletcher, '77-78, p. 27): "Glacial striæ were observed near Cape Gabarus, running N. 60° E., crossed by finer ones in a direction N. 40° E., the rocks being finely smoothed, polished, and rounded. On the path from Framboise road to the church, striæ rocks, seemingly in place, run N. 25° E. and N. 70° E., the latter being the most recent."

From the writings of Mr. E. Gilpin I find the following (Gilpin, '86, p. 526): "Around Sydney Harbor and to the east and south of Sydney, the striæ are observed chiefly on the millstone grit, and vary between S. 45° W. and S. 78° W. magnetic. Similar courses are met with at East Bay, Gabarus Bay, Framboise, and other points on the south shore." The variation here is roughly about 25° W., so these striæ are thus equal to S. 20° W. and S. 52° W. true. He says there are no moraines, but mentions erratic boulders. "The erratic boulders found over these measures [Carbonic districts] are derived from the neighboring subdivisions of the felsitic and syenitic series, and have seldom travelled far" (p. 525).

Dr. Honeyman gives some interesting facts as follows (Honeyman, '90, p. 343): "The occurrence of the grooves on the verge of the sea, like corresponding phenomena observed in Nova Scotia, unmistakably show that an impulse was communicated from beyond Nova Scotia and Cape Breton, and that the glaciers of both are only members of a great glacier system, which comprehended both Nova Scotia and Cape Breton;" and also (p. 354), "The glaciation of Green Point suggests influences from beyond like the transportation on the Gulf shore in Antigonish County, and the glaciation on the verge of Cleveland Iron Mountain, Nictaux, and on the Canaan road, Aylesford."

3. *The interlobate region.*

Assuming that the hypothesis is true, and that a great lobe of ice extended from Newfoundland southwesterly along the coast to Cape Cod and Nantucket, we would have an interlobate belt between this lobe and the ice moving southeasterly in New England from the Labrador ice-sheet. This interlobate belt would probably coincide with the New Brunswick coastline of the Bay of Fundy, passing a short distance off the New England coast, until Massachusetts is reached, when it would encroach upon the land southward from the vicinity of Boston. The greater portion of this belt, lying as it does out to sea, is not available for investigation, but those portions which impinge upon the land reveal, as we shall see, some interesting facts which are not only entirely in accord with, but support, the hypothesis.

The high and well-defined morainal ridge running approximately north and south from Wood's Hole on Cape Cod to Manomet Hill near Plymouth, and with ice-contact slopes on both sides, has already been pointed out, as well as the great differences in the nature of the morainal material on one side from that on the other.

A projection of this interlobate line northward will be seen to pass close to Boston on the east, and be intercepted by the salient of Cape Ann. Both these localities present peculiarities which seem best explained by the presence in those regions of this eastern lobe, and will now be considered.

THE BOSTON BASIN.

In a paper entitled "Distribution and Probable Age of the Fossil Shells in the Drumlins of the Boston Basin" by W. O. Crosby and H. O. Ballard (Ballard, '94, and Crosby, '94, 2), the authors quote Upham as saying these shells were ploughed up from Boston Harbor by the ice

(p. 487). The map on page 488 shows the localities in which these shells have been found to constitute a broad belt from the neighborhood of Boston, southeast to Cohasset, or south of Boston Harbor. Now this distribution would not be so likely to result from ice moving from the land, especially if it had at that time the considerable easting in this basin indicated by the striæ, but is exactly what would be expected to result from the gouging of the sea floor by ice coming from the northeast, which was the direction of motion in Nantucket and Cape Cod.

The local nature of the drift and till here is also what would be looked for in an interlobate region, and consequently one in which there was little motion to the ice. Professor Crosby says (Crosby, '94, 1, p. 271), "The extremely local origin of the main part of the till becomes very obvious, immediately on passing southward from the sedimentary rocks of Hingham to the broad area of granite;" and again (p. 273): "Of the local origin of the larger fragments, at least in the till, we have an impressive illustration in the numerous boulders on Prospect Hill. This large drumlin is something like Booth Hill in Scituate in being well sprinkled with boulders over a large part of its surface, but owing perhaps to aqueous erosion, which has swept away the finer material, they are especially abundant on the southwest and south side of the hill, these slopes being the most remarkable boulder-fields observed in the South Shore district, and recalling the boulder-clad areas of Cape Ann. But among these thousands of boulders of all sizes, from 6 inches to 6 feet or more in diameter, Mr. Bouvé and I have observed very few that are not granite, and certainly the sedimentary and volcanic rocks of northern Hingham are very sparingly represented."

In Vol. I, Part III, of the same work, in discussing the Blue Hills region, we find the statement (p. 549), "As in Hingham and Cohasset, the great majority of the boulders are of extremely local origin, being within say half a mile of the parent ledges, and only a small proportion of the whole can be proved to have travelled as much as five miles."

The glacial lakes of the Boston Basin, proved to have existed from the presence of numerous systems of sand-plains, are very interesting in connection with the hypothesis of a seaward lobe of ice. In referring to these sand-plains as fresh-water deposits, Professor Crosby says (Crosby, '93, p. 163) there is no evidence of marine erosion on the hard rocks above the present level of the sea, and also (Crosby, '94, p. 286) "... no traces of marine erosion or marine deposits or any proof of a postglacial elevation of the land" in Hingham, and that plains are best explained as the product of glacial lakes and streams during the departure of the ice-sheet.

As the glacial period came to a close and the ice began to melt back, the interlobate margins of the two lobes would recede from each other, leaving a region of interlobate glacial lakes held up by the surrounding ice, and varying in level from time to time through local causes.

Referring to the position of certain boulders, Professor Crosby says (Crosby, '93, p. 148): "The occurrence of these isolated blocks on the northern aspects of the hills, and at approximately the height of one of the principal sand-plains, is certainly suggestive of their transportation by floating ice, rather than the ice-sheet, and it appears necessary to regard them as having been derived from the granite ledges north of the Boston Basin, the nearest possible source of granite of this character. . . ."

Some very important observations which seem to confirm the presence of an interlobate lake are made by Mr. F. G. Clapp as follows (Clapp, '04, p. 199): "A fact thought to be of considerable significance is that plains having a common elevation are distributed over very wide areas. Deltas of the 170-foot series not only are known north and south of the Dover highlands and in the adjacent Neponset valley, but are very abundant across the divide of the Sudbury River in the vicinity of Cochituate, and even far down the valleys of the Sudbury and Concord rivers. The widespread distribution of plains of the same general elevation at first appears to indicate the presence in the region of a large open body of water, which, with successive retreats of the ice-margin, opening outlets for the lake at consecutive lower levels, allowed the water to fall repeatedly to the next stage below. Recent studies by Mr. M. L. Fuller in the Neponset basin indicate, however, that in that region there was no such simple sequence of events; and the present writer, working independently, finds evidence in Lake Charles, indicating that here too the open lake hypothesis can be accepted only in part." He says (p. 199) that Lake Shawmut, east of this, corresponds with later stages of the ice-retreat. This would seem to indicate that the ice drew off towards the northeast.

Mr. Clapp says also (p. 208): "The elevation of all the plains of the system [Newtonville-West Roxbury system] is very nearly or quite uniform, at about 150 feet above tide. Thus, notwithstanding the supposition that there can have been no large open lake in the region, there was certainly some connection between the lakelets adequate to maintain the water at a common level. The remnants of the decaying ice-sheet consisted of stagnant valley-blocks much broken up, the whole mass saturated with water, which was maintained at a uniform level consequent on some factor outside the Needham area. Into this basin were discharged torrents of water, which carried the gravels and deposited them upon, beneath, and between the ice masses." And also, "As the difference in elevation between the different plains of the series cannot be more than a few feet, it is evident that in the waters of the lakelets themselves or below their level, there can have been but little current." And still further (p. 211): "Plains of the Newtonville-West Roxbury type occur in the Medfield-Medway basin of the Charles River, and also in the Neponset valley. The uniformity of elevation over such a wide area strongly suggests dependence upon some lake-outlet east of the Neponset valley. No systematic search for such an eastern outlet has been made in the field, but it is known that in the southern watersheds of the Charles and Neponset rivers, there is no pass lower than 200 feet above tide."

He reaches the following conclusions (p. 214): —

"1. That the ice decayed *in situ* for many miles back from the ice-front — the decaying glacier consisting of a mass of stagnant ice, overlain and buried by sheets of water and by extensive deposits of sand and gravel.

"2. The more rapid disappearance of the ice on the west than farther east, causing a nearly open lake in parts of Sudbury valley, while as yet the ice in the lower portions of the Boston Basin had not decayed sufficiently to allow the formation of a single sand-plain.

"3. The interdependence of the water levels of the individual lakelets belonging to each stage, and their correspondence with some common outlet towards the sea."

Professor J. B. Woodworth has remarked the fact of the more rapid disappearance of the ice on the west than farther east, for he says (Woodworth, '03, p. 194), "In a paper now in preparation I purpose to show that in the southern part of Massachusetts the last ice-sheet existed longer, along and off the coast, than it did on the mainland west of Cape Cod Bay, thus allowing the formation and temporary existence of what may be termed proglacial lakes, or bodies of fresh water, held in front of the ice by a glacier-dam crossing the mouths of valleys, already freed from ice: such a body of water as Professor Crosby has claimed may have existed in Boston harbor, and even northward along the coast." And in writing me and in referring to the fact noted by Grabau that the plains about Wellfleet on Cape Cod were built inward towards Cape Cod Bay by the outwash or offwash from ice lying on the east of the arm of the Cape, he says: "I find this same thing true of the plains about Plymouth, Massachusetts, and it is on this kind of evidence found in various plains and proglacial lakes in this field that the conclusion rests."

The facts then under consideration in this basin show the former presence here at the close of the glacial period of a body of fresh water extending over a large area, broken by highlands and residual masses of stagnant ice, but still a hydrostatic unit, and held up on the east by an unstable barrier, which could have been no other than the ice of the Nantucket lobe which we have noticed a short distance to the southeast.

CAPE ANN

The peninsula of Cape Ann presents some phenomena which seem to indicate the presence of this seaward lobe in that region. The facts which seem to support this view are (1) the slight glacial erosion, (2) the local origin of the drift, (3) the shoved moraines, (4) two sets of striæ, and (5) the raised beaches.

(1) Professor Shaler mentions (Shaler, '68) some interglacial, fossiliferous beds near Gloucester, which were overridden by the ice, and, although consisting of sands and sandy clays, suffered removal only of their upper members.

Professor R. S. Tarr also mentions (Tarr, '05, p. 166) interglacial beds here as showing slight glacial erosion, and shows that decayed granite and boulders of disintegration were not removed from the bed rock, but are found in place. He cites this region as an example of moderate glacial erosion, and concludes as follows (p. 171): "That glacial erosion failed to remove the products of preglacial decay on Cape Ann is evident from the facts stated above; and that the marked accumulation of boulders on the Cape is due to this lack of erosive power, is advanced as a theory toward which all facts point, while no facts at present known oppose it. Whether there are reasons why the ice was locally thus ineffective, or whether it is a common condition along the New England coast, I cannot say. The Cape is a moderate salient against which ice-currents may have divided, leaving this region only slightly affected by its erosive action. Facts from a wider area must be obtained to settle the question whether this condition is local or general along the New England coast."

(2) The local origin of the drift is also pointed out by Professor Tarr in the same paper (p. 164), where he says: "It is no overestimate to state that there are tens of thousands of boulders on the Cape, and that fully 90 per cent of these are of local origin, especially granite, of which the Cape is chiefly made. So far no satisfactory explanation of this marked accumulation of local boulders has been proposed."

(3) Professor Shaler mentions the shoved moraines (Shaler, '87–88, p. 546), which he says have an average thickness exceeding 50 feet, and are "arranged in the form of rudely parallel ridges, which extend from N. 25° to 40° E. and S. 25° to 40° W." And also that, "The most remarkable feature observable in this morainal matter is the extreme

abundance of large erratics which it contains." Professor Shaler points out (p. 552) that the material of these moraines has a washed appearance, with very little clay.

The direction of the moraines indicates that the shoving force came from the northwest, and if we consider the seaward lobe to have begun to melt back here before the landward ice became stagnant, the moraines, if interlobate, relieved of the seaward pressure, would have been shoved by the ice coming off the land from the northwest, and the finer materials would have been washed out by streams or the waters of the lake which would undoubtedly have occupied this interlobate area. Many of the effects produced along this belt toward the close of the glacial period were of course local, the landward ice melting back at one point, as at Boston, and advancing slightly at another, as at Cape Ann, while the seaward lobe still remained as an unstable barrier off the coast.

(4) In regard to the glacial scratches, Professor Shaler says (Shaler, '87–88, p. 557), "The character of the rocks on Cape Ann, as well as the extensive covering of glacial waste, makes it difficult to ascertain the movement of the ice during the last glacial period;" and further (p. 557), "They indicate that, in general, the course of the ice movement was from the northwest or between that point and north;" but he says that between Pigeon Cove and Folly Cove: "Observations show two successive directions of glacial scratches, the one trending from northwest to southeast, the other passing from north to south. Of these, the scratches extending from northwest to southeast appear to have been the last formed."

He indicates these on the map (Plate LXXV), and also shows some having a northeast and southwest direction as well as some running east and west. If the shoving of the moraines was due to the causes I have indicated, we should expect the northwest and southeast striæ to be the last formed. The northeast and southwest and east and west striæ will be noticed on the map as occupying the most seaward portion of the region, and may have been formed by the seaward ice coming from that direction.

(5) The elevated beaches at Cape Ann are discussed in a paper by Professor Tarr with a note by J. B. Woodworth (Tarr, '03, p. 124). Professor Tarr has traced a number of elevated beaches, bars, and areas of ancient sand-dunes, and Woodworth has traced other elevated beaches in another part of the Cape. These formations seem to show the existence, toward the close of the glacial period, of water at an elevation of at least 40 to 60 feet above the present level of the sea, but the deposits in question are generally small in extent and isolated in character, and a fact that appears most significant is the apparent absolute absence

of fossils. Professor Tarr remarks on this absence (p. 188): "One of the reasons for not having previously published the evidence of former depression of the land in Cape Ann has been the hope, long deferred, that fossils might be found in some of the deposits. I have searched with care in every cut that I have seen on Cape Ann in the last sixteen years, and have never found a single fossil in the deposits of postglacial age. With the abundance of such fossils in the beaches farther north, as in Baffin Land, this absence of organic remains seems difficult to explain, and for a long time led me to question whether some other explanation of the phenomena at Cape Ann could not be suggested; but the evidence of depression seems so perfect that, notwithstanding the absence of fossils, I feel convinced, and I am obliged to assume that their absence is to be accounted for by adverse conditions, such as the short stand of the land, and the coldness and muddiness of the water. It must be confessed that when one finds an abundance of animal life at the very base of the Greenland glacier, in such a position as to be thrown to the surface when icebergs break away from the glacier, this explanation seems weak. However, the deposits on Cape Ann were made at the edge of a rapidly retreating ice-front, and marine life may not have advanced this far while the land was lower.

"It is, of course, possible that fossils exist here, but have not yet been detected. I have been told of the former discovery of fossils in a number of places, but evidence of this kind is of little value; and each time that I have looked where they were once found, it has been discovered that they no longer occurred there."

As Professor Tarr says, the absence of any trace of fossils in a marine beach seems difficult to explain, and it would seem as if some other explanation of the phenomena, and for which he sought, could now be given. If we consider that these are not marine beaches, but those of a glacial lake formed between the two lobes toward the close of the glacial period, when the interlobate margins of the two lobes began to melt away from each other, we have an explanation of the absence of the fossils which does not even require a postglacial elevation of the land, while it seems to be perfectly in accord with all the other facts observed. It may be found later that some of the non-fossiliferous elevated beaches in regions farther north owe their origin to the same cause.

Farther up the coast, the interlobate belt lies apparently out to sea, so that we are unable at present to obtain from this region any additional facts, beyond the apparent slowing up of the ice on the outlying islands of Maine, and an occasional change of motion to a southwesterly direction, noted at several points along the coast. De Laski says (De Laski, '61), speaking of the striæ in Vinal Haven, that none of the scratches are deep, but are delicate and regular, as if made by slow and straightly moving ice. While this would be expected near the ice-margin, the fact that the ice was at least 1500 feet thick on Mt. Desert Island might seem to indicate that considerable motion was prevented by some seaward barrier.

In regard to change of direction near the coast, Professor Hitchcock mentions striæ at Cape Elizabeth and at Saco, Maine, with a direction somewhat west of south (Hitchcock, '78, p. 195), and says (p. 211): "Those nearer the coast might be referred possibly to iceberg agency, or to some connection with the ocean. They are, at Cape Elizabeth, close to the salt water, S. 8° W.; at Limington, Maine., S. 33° W., numerous and well marked for half a mile's distance, seen in crossing a hill; at Danville Junction, Maine, a little west of south; and at Bow Lake in Strafford, S. 31° and 58° W. The usual direction in this neighborhood is fairly at right angles with these. Is it possible that these are scanty relics of a once abundant southwest glaciation? Some of the lenticular hills, about to be described, are arranged in a line suggestive of a connection with a southwesterly current, much more extensive than is indicated by the striæ."

If it should be shown that there once had been an "abundant southwest glaciation" here, then the interpretation would seem to me to be that the Newfoundland ice-sheet, having the more favorable position for receiving the precipitation from the moisture-laden ocean winds, developed somewhat earlier than the Labrador ice-sheet, and the Nantucket lobe reached southeastern New England ahead of the ice from Labrador, so that, unopposed, it was able to push its front for some distance over the land to the southwest, until it was turned seaward by the arrival of the Labrador ice. An equilibrium between the two opposing forces then became established, the interlobate belt formed, and the characteristic deposits accumulated.

If it should ever be shown that the Carbonic conglomerate in the Narragansett basin had its origin as an ancient glacial deposit, as some have thought, the presence in it of Cambric pebbles identical in composition with those in the late drift of the Nantucket lobe, which, there seems to be some reason to believe, were derived from Newfoundland, we should have the interesting speculation whether similar conditions ever existed in Carbonic times. This hypothesis would, however, certainly require very convincing proofs.

4. *Transported material.*

The detrital material in the region occupied by the Nantucket lobe is peculiar if considered as transported by a seaward extension of the ice-sheet of southern New England. West of the interlobate belt erratics can be traced back to outcrops of rocks from which they were derived, but east of this belt the material is entirely different, and its source a question of speculation to which no definite answer has been given. As Professor Shaler has pointed out (Shaler, '89, p. 26), nearly one-half of the pebbles of the stratified gravels on Nantucket are derived from granitic rocks, a considerable part of the remainder being composed of felsites, felsite-porphyries, volcanic breccias, and stratified rocks, clays, slates, sandstones, and conglomerates. He considers the neighboring mainland and the region of Boston, Massachusetts, as the source of the granites and felsites, but says (p. 26), "In the region about Sankaty Head, these porphyritic pebbles are plentifully intermingled with somewhat angular fragments of volcanic breccias of a type unknown to me in any part of southern New England, though they much resemble the ash beds and breccias of the eastern portion of the shore of Maine, especially those found near Eastport."

Some of the conglomerates and sandstones are of Carbonic age, and might be thought to be derived from the Coal Measures of Rhode Island, the nearest known area able to furnish this sort of material, but Nantucket is separated from this area by the interlobate moraine, and moreover, as Professor Shaler says (p. 27), "If we assume that the direction of the ice movement at the time when the Nantucket moraine was formed, was at right angles to the frontal line of that moraine, then these materials derived from the volcanic and the Carboniferous rocks probably could not have come from any part of the Narragansett field: they must have been derived from deposits of that age which lie either below the surface of Cape Cod, or under the ocean to the north or south of it. The extreme western limit whence they could have journeyed must have been a meridional line, lying at least ten miles east of Boston. In general, it is a tolerably fair assumption that an extended moraine front was formed by an ice-stream, which moved down at right angles to the line of the accumulations. I am therefore disposed to believe that all the glacial waste of Nantucket, except perhaps the boulders transported by icebergs, came from far east of the Narragansett basin." I might mention also that I found in the stratified glacial gravels at Highlands, on Cape Cod, a small thin piece of what appeared to be coal, much decayed, which formed a dark streak in the gravels, and crumbled to pieces on removal.

If the ice came from so distant a region as Newfoundland, these Carbonic rocks could well have been derived from areas in Nova Scotia and Cape Breton Island.

In the detrital material deposited by the Nantucket lobe are found some interesting Cambric pebbles and boulders. Some of these have been found on Martha's Vineyard, Nantucket, and Cape Cod, and along the interlobate belt northward to Nahant. Dr. A. W. Grabau says of these (Grabau, '03, p. 606): "In 1891 Mr. Watson found a small boulder of red limestone on Pleasant Beach, Cohasset, a second at Sandy Cove, and in 1894 a third one of the same character at Bass Point, Nahant. The finding of these boulders leads to the supposition that a fifth locality for Lower Cambrian fossils occurs somewhere in eastern Massachusetts, as the probabilities are against the source of these boulders being in Rowley, where the prevailing material is grayish limestone similar to that of Nahant, while the red beds are of a more shaly character. The possibility that these boulders were carried here from some more northern locality, either by ice or as ballast, must not be overlooked.

"The first Cohasset boulder was forwarded to Mr. Walcott for examination, and he found in it *Hyolithes communis*, small var., and *Straparollina remota*. Mr. Walcott published a notice of this boulder in the Proceedings of the Biological Society of Washington, Vol. VII, p. 155, July, 1892. Besides the two species identified by Walcott, twelve other species have been found in the three boulders found by Mr. Watson. A mass of similar rock has since been discovered by Mr. Watson at Weymouth. In 1894 Mr. Watson found a pebble of dark reddish brown, calcareous slate at Nahant, west of the point known as John's Peril. On the bedding plane occurs a fragmentary cephalon of a trilobite here referred to *Agraulos (Strenuella) strenuous* and on the fracture face occur several cross-sections of the thorax."

Quartzite pebbles carrying Upper Cambric *Lingulas* have been met at different points within this region, and specimens of the same rock with *Scolithus* "were also found by Mr. Woodworth on Martha's Vineyard, on Nantucket, and near Duxbury, Massachusetts," p. 608.

Water-worn pebbles of the red, shaly Cambric limestone are found in abundance in the glacial gravels at Highlands, on Cape Cod, but are not always fossiliferous. Some, however, yield characteristic fossils, and one boulder from here is described by Dr. Arthur Hollick as follows (Hollick, '02, p. 385): "Boulder of red shale, of Cambrian age, containing numerous trilobite and other remains." It was submitted to Mr. C. F. Matthew of the Canadian Geological Survey, who gave the following note: "The fauna is evidently that of the Etcherminian red shale of the Boston Basin of Cambrian rocks. The fossils are in good condition of preservation; the shale is soft, and if you could find the original bed, no doubt a good series of fossils could be obtained." His identification includes the genera *Microdisus*, *Olenellus*, *Agraulos*, *Strenuella*, and *Hyolithes*. Other fragments were submitted to Mr. Gilbert Van Ingen, who communicated as follows: "Two of the species are trilobites of Lower or Middle Cambrian horizons; one is certainly *Microdiscus*, the other appears to be an *Olenellus*, but which species I cannot yet say. The material is fine, and I should like to see the ledge from which the fragment was originally removed."

Now these Cambric pebbles and boulders differ both in their contained faunas and their lithologic characters from any known outcrop of rock in New England, but are identical with Cambric rocks of Newfoundland, the shaly limestone being like that from Smith Point, and the quartzite like that from Great Bell Island in Conception Bay.[1]

Dr. A. A. Julien of Columbia University, who has passed many summers on Cape Cod, and so is well qualified to speak on the nature of the erratic material of that region, has kindly given me the following note: "In the study of the material of boulders and pebbles on Cape Cod, during a period of more than ten years, the following general conclusions have been impressed upon me. Nearly all are of crystalline rocks, predominantly of igneous types. Sedimentary forms do not occur except very rarely, not even massive conglomerate like those at Dorchester, Massachusetts, 60 miles to the northwest. An exception occurs in abundant small fragments of fissile slate at North Truro, probably derived from disintegration of large boulders.

"The igneous rocks are for the most part acidic. Basic varieties, such as the pyroxenites, diabases, gabbros, traps, etc., of eastern Massachusetts are entirely absent. In the gravel beds of the apron-plain along the south shore of the Cape, whose rounded pebbles present a far greater variety than the angular boulders of the moraines, igneous rocks of intermediate composition are not uncommon. These consist chiefly of rather fine-grained diorites of several kinds, hardly distinguishable from those occurring both in New England and Canada.

"The acidic igneous rocks which constitute the larger part of the pebbles of the gravel beds, and all the boulders of the moraines, never comprise, so far as my observations have gone, the easily distinguishable massive forms of granite and granite-gneiss, often porphyritic, of the coastal region of Maine, nor massive varieties rich in hornblende, like those of Quincy, Massachusetts.

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[1] Since writing the above, Mr. Guy R. B. Elliott, C. E., whose home is in Nova Scotia, informs me that water-worn pebbles of the same red shaly limestone, but averaging larger in size, are strewn in abundance along the western side of Nova Scotia, especially along the shore of the Bay of Fundy. He says also, that he knows of no local rock from which they could have been derived, and that they seem to be a part of the drift from the north.

"The predominating variety in Dennis, Brewster, Harwich, and Chatham is a coarsely laminated, micaceous granite-gneiss, often contorted and penetrated by veins and seams of coarse pegmatite. Another variety observed in huge boulders at South Chatham is a very coarse feldspathic granite or monzonite, rich in microcline and orthoclase, with a little hornblende. This last in particular belongs unmistakably to the Laurentian of Canada, but no fragment of the anorthosite of Labrador has ever been found."

Summary

The facts in regard to the region under consideration set forth in the preceding pages are briefly as follows: The present land mass of Newfoundland shows evidences of great glaciation and the former presence of moving masses of ice of enormous thickness, while a probable elevation of not over 1000 feet during the glacial period would have added to the present area as dry land all that adjacent portion of the sea floor within the 1000-foot contour. This would have included the Grand Banks and the region to the edge of the continental shelf, an area which would represent an ice-sheet of no small magnitude. The position of this region with regard to moisture-laden winds from the ocean is also so favorable for precipitation as to have probably resulted in the formation of an ice-sheet of great activity. The present land of Newfoundland also shows from the glacial grooves and scratches and ice-worn topographic features, that the general motion of the ice was to the southwest or northeast, probably both directions from a central radiant point, as there are indications of a fanning of the ice seaward from the eastern end of the island.

The southwesterly direction is continued in Cape Breton Island, where the effects produced are evidently too great to be the work of local glaciers; in northern Nova Scotia; the eastern part of Prince Edward Island; and along the Bay of Fundy, with more of a fanning to the south and southeast in the southern part and along the southeastern coast of Nova Scotia. Continuing this southerly direction still farther across the Gulf of Maine, we come finally to Cape Cod, Nantucket, and eastern Martha's Vineyard, with evidence here of the ice having come from the northeast, and the presence of erratics, which seem not to have been derived from the neighboring mainland, but are apparently identical with rocks of Newfoundland, Nova Scotia, and adjacent regions. Moreover, we find a north and south interlobate moraine on Cape Cod separating these deposits from those of known origin to the west, and this interlobate moraine seems to be represented farther north by interlobate conditions wherever this belt impinges sufficiently upon the land to be available for investigation. And finally, all the phenomena along this belt seem best in accord with the hypothesis of the presence of a lobe of ice lying out to sea after the landward ice had begun to melt back at the close of the glacial period.

Conclusion

From the foregoing facts, it would seem as if we had evidence enough to seriously consider the possibility of the former existence of an active ice-sheet on Newfoundland, and indeed, I can hardly see how we can escape the belief that during the last glacial period this Newfoundland area was occupied by an ice-sheet of such magnitude and such activity as to be able to send its lobes and glaciers to the edge of the continental shelf, and southwesterly even as far as Cape Cod and Nantucket.

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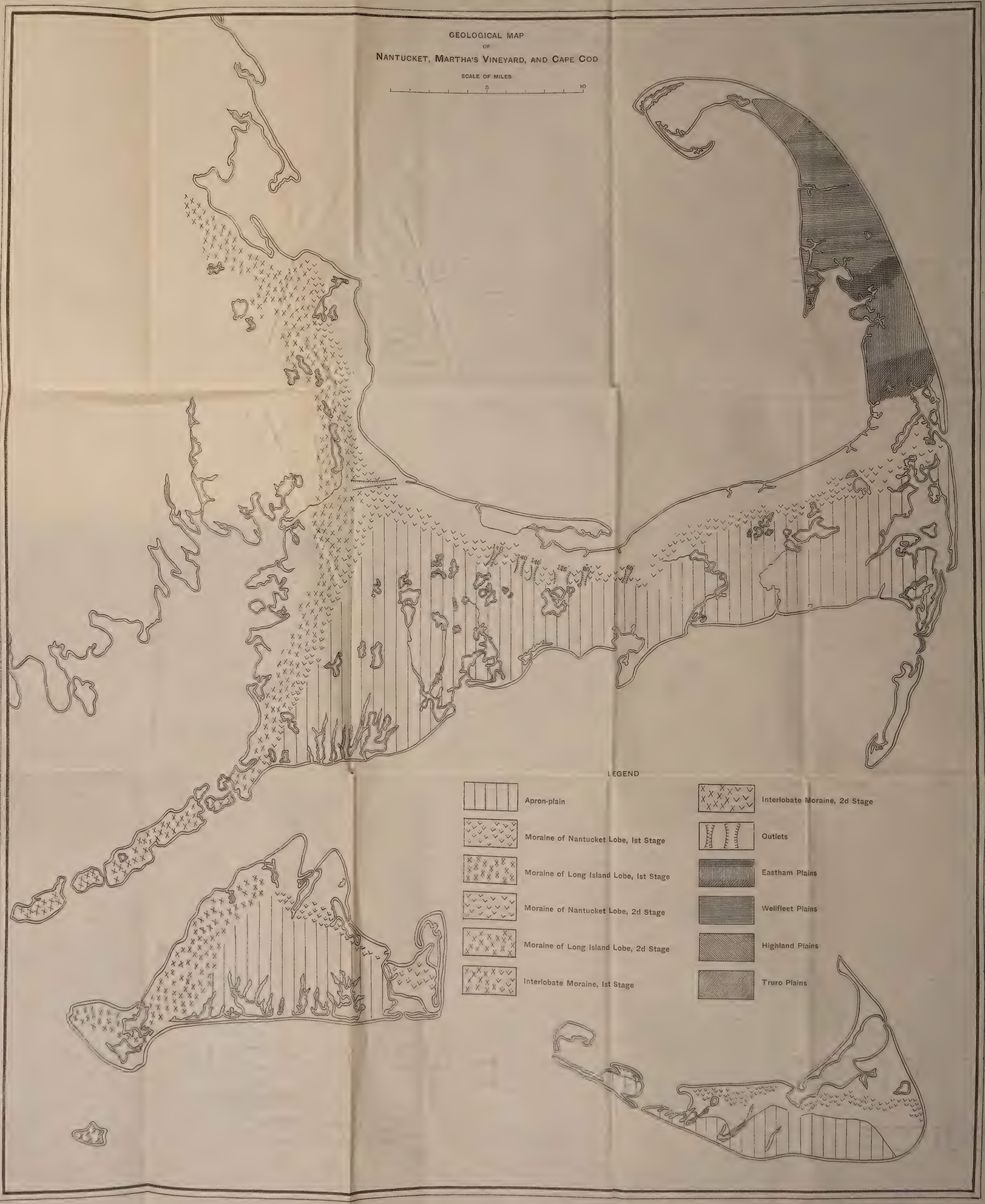
GEOLOGICAL MAP
OF
NANTUCKET, MARTHA'S VINEYARD, AND CAPE COD
SCALE OF MILES
5
10
140
140
140
125
80
60
LEGEND
Apron-plain
Moraine of Nantucket Lobe, Ist Stage
Moraine of Long Island Lobe, Ist Stage
Moraine of Nantucket Lobe, 2d Stage
Moraine of Long Island Lobe, 2d Stage
Interlobate Moraine, Ist Stage
Interlobate Moraine, 2d Stage
Outlets
Eastham Plains
Wellfleet Plains
Highland Plains
Truro Plains

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PLATE XXXV

GEOLOGICAL MAP
OF THE
ISLAND OF NANTUCKET

SCALE OF MILES

LEGEND

Kame Hills

Ice-contact Slope

Apron-plain

The fosse is the irregular blank space between the kame hills and apron-plain.

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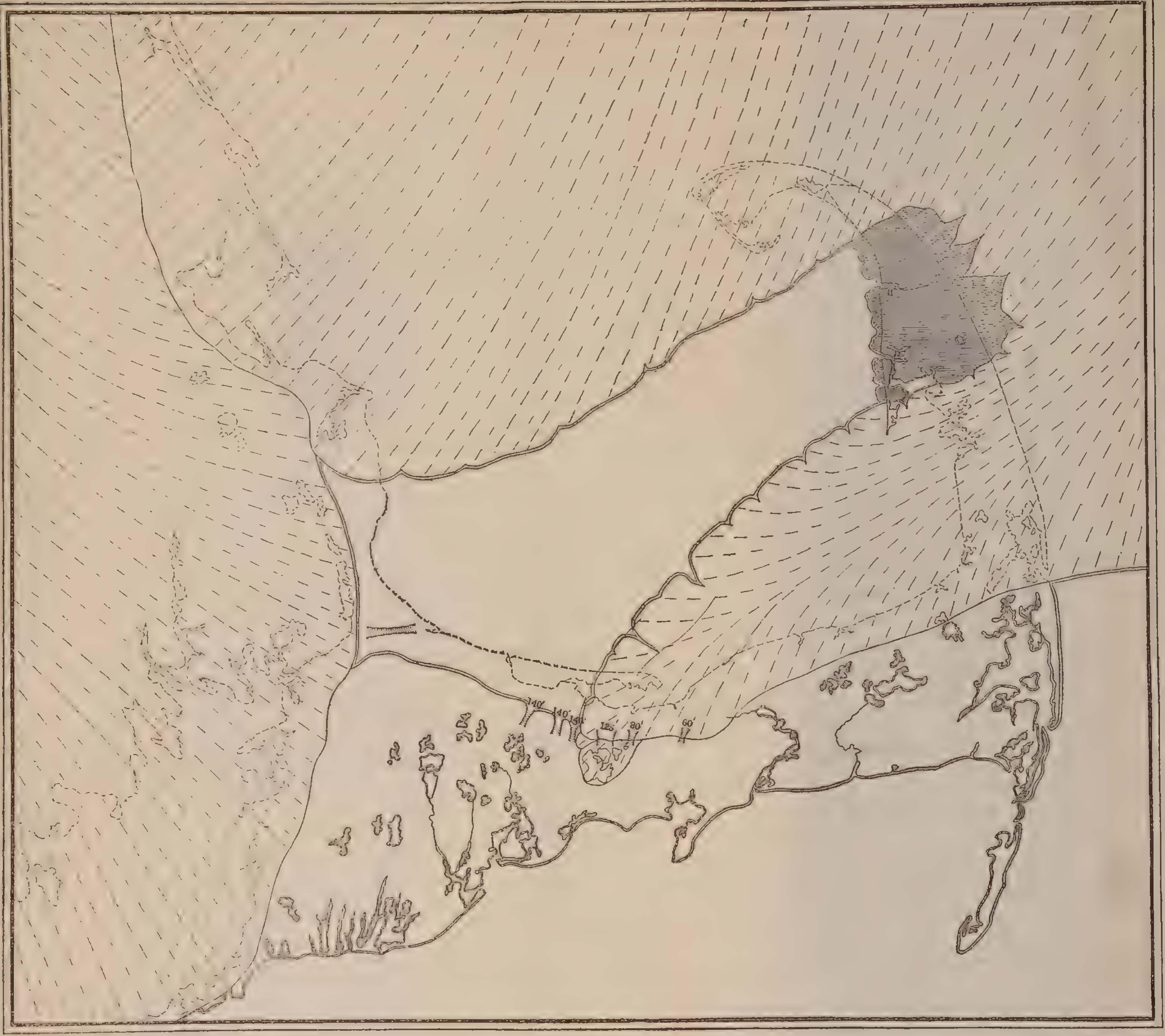

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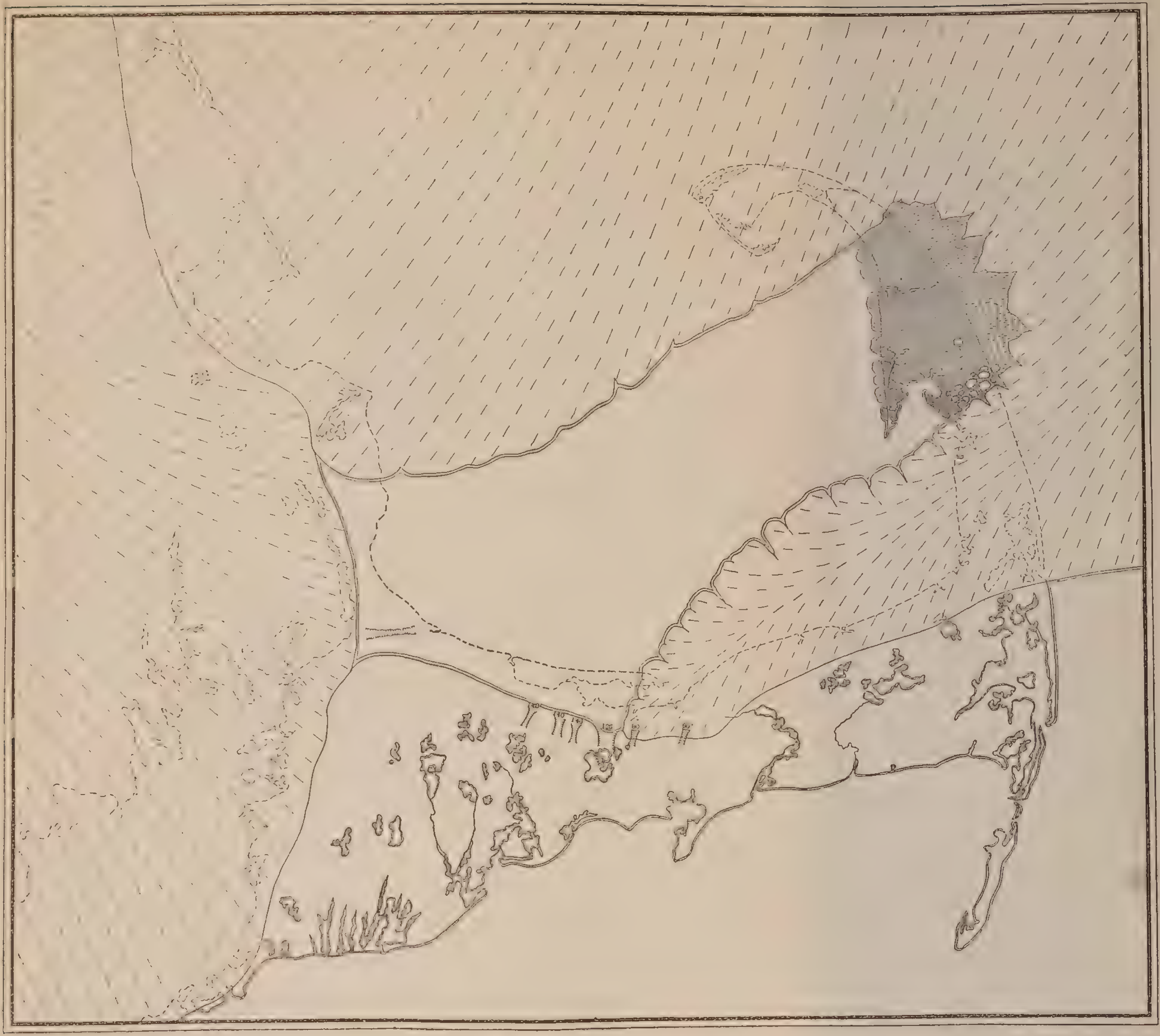

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